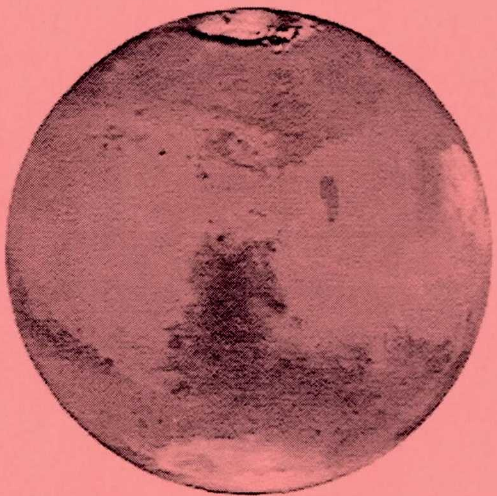
Concepts and Approaches for Mars Exploration

Part 2



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CONCEPTS AND APPROACHES FOR MARS EXPLORATION

Part 2

Hosted by

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Preface

This volume contains abstracts that have been accepted for presentation at the Concepts and Approaches for Mars Exploration workshop, July 18–20, 2000.

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MARS EXPLORATION WITH A SELF-REFUELING HOPPER. Geoffrey A. Landis[1] and Diane Linne[2], [1]Ohio Aerospace Institute, NASA John Glenn Research Center mailstop 302-1, 21000 Brookpark Road, Cleveland OH 44135; e-mail geoffrey.landis@grc.nasa.gov, [2] NASA John Glenn Research Center, mailstop 5-10, Cleveland, OH 44135; e-mail Diane.L.Linne@grc.nasa.gov

Introduction: A small reusable "hopper" vehicle, the Mars In-situ Propellants Rocket, is proposed to fly autonomously on Mars, using *in-Situ propellant production* to manufacture rocket propellant directly out of the Martian atmosphere [1]. The MIPR explores the Martian surface under rocket power and can repeatedly takeoff and land, carrying a suite of science instruments over a range of hundreds of meters per hop. The flight demonstration will accomplish a range of technology objectives important to both unmanned probes and to future human missions, including:

demonstration of a sub-orbital Mars launch vehicle

demonstration of a pressure-fed small propulsion system for Mars ascent vehicles

demonstration of a lightweight space engine

and

use for the first time of propellants manufactured in-situ on another planetary body.

In addition to these technology objectives, the MIPR vehicle can carry a science payload that will advance our understanding of the surface and atmosphere of Mars.

Discussion: The Mars Pathfinder mission convincingly demonstrated the value of mobility on a planetary surface, and even though the *Sojourner* rover crawled at less than half a meter per second, and wandered no more than a maximum of twelve meters from the lander, the scientific (and public outreach) value of the *Sojourner* rover was incalculable.

But surface rovers, limited by terrain, cannot explore many interesting territories. If a vehicle were to rise above the surface, it could traverse "impassible" chasms and hop over "uncrossable" cliffs.

A valuable surface explorer would be a rocket-powered hopper able to take off and land repeatedly, carrying a suite of science instruments over hundreds of meters per hop.

The rocket-powered hopper with these key features can achieve such objectives:

- refuels itself autonomously for multiple hops by using solar power to react atmospheric CO_2 into O_2 (oxidizer) and carbon monoxide (CO) (fuel);
- achieves an altitude of several hundreds of meters and traverses a distance of several hundreds of meters during each hop; and
- carries a suite of scientific instruments to a soft landing at the conclusion of each hop.

The hopper will be situated on the science deck of a Surveyor class Mars lander. Once the lander sets down on Mars, the solar arrays will begin to produce power to operate its propellant production plant. The available power will determine the production rate.

The propellant production system is based on the MIP demonstration unit, which is a flight-qualified production plant originally designed to fly on the [now postponed] Mars-2001 Surveyor mission [2]. Our preliminary designs indicate that the production plant will be at least half of the hopper's dry mass. The distance achieved during a hop is a function of launch angle, quantity of propellants, thrust, and dry mass. For initial planning purposes, we have assumed a launch angle of 45° to maximize range. As a technology goal, we want to demonstrate an engine large enough that it can be scaled up for a Mars sample-return mission, where required thrust is expected to be 1700 to 2200 N (400 to 500 lbf). However, it is also important to keep hopper thrust levels low—to minimize mass and to allow a soft landing after each hop. We anticipate engine thrust to be 200 to 700 N (50 to 150 lbf) and are using a thrust level of 350 N (75 lbf) for planning purposes.

Parameters for the candidate vehicle are shown in table 1.

The nature of the hop, therefore, can be described by the dry mass of the vehicle (i.e., the mass to be landed back onto the Martian surface), the O_2 and CO production rates (measured in standard cubic centimeters per minute (sccm)), and the length of time between hops. For example, we have estimated that for 20 kg of dry mass and a production rate of 20 sccm of O_2, the hopper can jump 500 meters every 25 days. For 30 kg of dry mass and a production rate of 40 sccm of O_2, the hopper can jump 1000 meters every 25 days.

Table 1
Mars In-Situ Propellant Ballistic Hopper

Single Hop Range:	0.50 kilometers
Engine Thrust:	335 N (75 lbf)
Engine I_{sp}:	250 sec
Propellants:	O_2/CO (gas)
Total Mass	20.3 kg
Duration Between Hops:	25 days

Sounding Rocket: A proposed alternate vehicle is the Mars sounding rocket. This would be a single-launch vehicle, but it might deploy several payloads to multiple locations. It could be designed for a semi-soft or hard landing but could not be refueled for a second flight. The sounding rocket would obtain the same aerial science data as the hopper (although for only a single flight) and surface information at a single or multiple sites. It could also demonstrate the use of in-situ produced fuel, although for this option the propellant production plant would not be carried onboard. This would greatly reduce its dry mass and thereby allow the single flight to achieve a higher altitude, a longer range, a larger payload, or some combination of all three.

Science: The vehicle serves as a science platform that complements ground and orbital observations. Possible science payloads for the vehicle include:

Aerial photography of landing site. The aerial view of the landing site will be invaluable for placing geological investigations in a proper context. We will get high-detail images at a different sun angle and from a different physical perspective than the images taken by the descent imager during landing. Thus, our aerial images will complement the science data obtained from other means. These images will also provide "aerial reconnaissance" for selecting traverse path and locating interesting targets for rover samples.

Meteorology. Studies of Martian climate and meteorology will benefit greatly from an expanded range of altitudes for temperature and wind measurements.

Vertical profile of aerosols. The aerosols suspended in the Mars atmosphere are a significant climate and meteorology driver; the hopper/sounding rocket scientific payload will measure the vertical profile and investigate the change in optical scattering properties of the dust as a function of altitude.

Geological measurements at isolated remote sites. Since the vehicle easily traverses obstacles that rovers cannot, we will be able to sample regions that are geologically interesting but too rugged for surface rovers to reach.

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MATE AND DART: AN INSTRUMENT PACKAGE FOR CHARACTERIZING SOLAR ENERGY AND ATMOSPHERIC DUST ON MARS.

Geoffrey A. Landis[1], Phillip Jenkins[1], David Scheiman[1], and Cosmo Baraona[2], [1]Ohio Aerospace Institute, NASA Glenn Research Center mailstop 302-1, Cleveland OH 44135, e-mail geoffrey.landis@grc.nasa.gov, [2]NASA Glenn Research Center mailstop 302-1, Cleveland OH 44135, e-mail cosmo.baraona@grc.nasa.gov.

Introduction: The MATE ("Mars Array Technology Experiment" [1]) and DART ("Dust Accumulation and Removal Test" [2]) instruments were developed to fly as part of the MIP experiment on the [now postponed] Mars-2001 Surveyor Lander [3]. MATE characterizes the solar energy reaching the surface of Mars, and measures the performance and degradation of solar cells under Martian conditions. DART characterizes the dust environment of Mars, measures the effect of settled dust on solar arrays, and investigates methods to mitigate power loss due to dust accumulation.

MATE

MATE Purpose: Until Mars Pathfinder landed in July 1997, no solar array had been used on the surface of Mars. The MATE package is intended to characterize the environment of Mars in order to gather baseline information required for designing power systems for long duration missions, and to quantify the performance of advanced solar cells on the surface of Mars.

MATE will measure the performance of five different individual solar cell types and two different solar cell strings.

MATE Solar Characterization Sensors: To measure the properties of sunlight reaching the Martian surface, MATE incorporates two radiometers and a visible/NIR spectrometer.

The radiometers consist of multiple thermocouple junctions using thin film technology. These devices generate a voltage proportional to the solar intensity. One radiometer measures the global broadband solar intensity, including both the direct and scattered sunlight, with an approximately 130° field of view. The second radiometer incorporates a slit to make a measurement of the direct (unscattered) intensity radiation. The direct radiometer can only be read once per day, with the sun overhead.

The spectrometer measures the global solar spectrum with a 256-element silicon photodiode array, sensitive in the visible range (300 to 1100 nm), and an second InGaAs photodiode array, sensitive to the near infrared (900 to 1700 nm). The spectrometer range covers 86% of the total energy from the sun, in approximately 5 nm resolution. Each photodiode array has its own fiber optic feed and grating.

Although the purpose of the MATE is to gather data of utility to designing solar arrays for Mars surface power systems, the radiometer and spectrometer measurements are expected to also provide important scientific data in characterizing the properties of suspended atmospheric dust.

DART

DART purpose: Dust deposition could be a significant problem for photovoltaic array operation for long duration missions on the surface of Mars. Measurements made by Pathfinder showed 0.3% loss of solar array performance per day due to dust obscuration [4,5]. Thus, dust deposition is the limiting factor in the lifetime of solar arrays for power systems on Mars, and developing design tools to mitigate this deposition is important for extended mission duration.

The DART experiment is designed to quantify dust deposition from the Mars atmosphere, measure the properties of settled dust, measure the effect of dust deposition on the array performance, and test several methods of mitigating the effect of settled dust on a solar array. Although the purpose of DART is to gather information critical to the design of future power systems on the surface of Mars, the dust characterization instrumentation on DART will also provide significant scientific data on the properties of settled atmospheric dust.

Dust characterization on DART is done by two instruments: the dust microscope and the "MAE" commandable dust cover. The dust mitigation tests on DART consist of two tests: the tilted cell tests, and the electrostatic dust repulsion test. In addition, DART will have a set of sun position sensors.

Microscope. The DART microscope is a fixed-focus microscope, which images a transparent glass settling plate from below. As atmospheric dust settles on this settling plate, it is imaged. The microscope uses a 40X objective, which focuses onto a 512x512 pixel focal plane array. The microscope resolution is about 0.5 microns.

Total mass of the microscope is 200 grams.

The microscope is intended to furnish information about the size distribution of the settled dust. Since settled dust may be different in character from the dust, which remains suspended in the atmosphere, this information is of considerable interest to the design of

dust mitigation strategies. For the larger particles, the DART microscope will also yield shape information.

Dust coverage measurement. The "MAE" dust cover is based on the experiment flown on Pathfinder [4], and consists of a transparent plate onto which dust settles. This plate is located above three small solar cells, used in short-circuit current mode as solar intensity measurement in three wavelength bands. A mechanism allows the cover to be rotated away from the cells. Comparison of the cell output with the dust-covered plate in position and removed measures the dust coverage independently of other changes in the cell performance or the atmosphere. By taking a spectrum of the sunlight through the MAE settling plate, we can also obtain a transmission spectrum of the settled dust.

Dust Mitigation Experiments. Measurements of the camera window on the Viking lander showed no dust adhering to the vertical surface. Observations of the thermal shell of the Viking landers seemed to show that dust also did not build up on the tilted surfaces. Unfortunately, no quantitative measurement of accumulation could be made. A high priority is therefore to see whether tilted solar cells avoid accumulation of dust, and to find what angle is required to avoid dust coverage. The tilted cell measurement consists of solar cells tilted at 30°, 45°, and 60°, plus a horizontal control, plus a solar cell tilted at 30° with low friction (diamond-like carbon) coating.

Martian atmospheric dust is expected to be charged. In order to test whether electrostatic fields can be used to mitigate the deposition of dust on solar arrays, the electrostatic experiment will test three configurations. A high-voltage solar cell provides a potential of about 80 volts to a transparent conductor on the front surface of the solar cell coverglass. Three configurations are tested: positive potential applied to the cell cover, negative potential applied to the cell, and transverse field across the cell. These will be compared to the control cell with no applied potential.

Sun Position Sensors. Finally, the DART experiment includes a set of three sun position sensors, each consisting of a cylindrical lens focusing light onto a 512-element linear photodiode array. The sun position sensors have a mass of 18 grams each.

Summary: The MATE and DART experiments, designed for the Mars-2001 Surveyor Lander mission, contain a capable suite of sensors which provide both scientific information as well as important engineering data on the operation of solar power systems on Mars. MATE will characterize the intensity and spectrum of the solar radiation on Mars. DART will measure the dust accumulation rate, the transmitted spectrum of the dust, and will image individual settled particles to determine the size distribution and the particle shape, as well as gathering information on electrostatic properties.

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ANAEROBIC NITROGEN FIXERS ON MARS. B. G. Lewis, Dept. of Civil Engineering, Northwestern University, Evanston, IL 60208. Email: b-lewis@northwestern.edu

The conversion of atmospheric nitrogen gas to the protein of living systems is an amazing process of nature. The first step in the process is biological nitrogen fixation, the transformation of N_2 to NH_3. The phenomenon is crucial for feeding the billions of our species on Earth. On Mars, the same process may allow us to discover how life can adapt to a hostile environment, and render it habitable.

Hostile environments also exist on Earth. For example, nothing grows in coal refuse piles due to the oxidation of pyrite and marcasite to sulfuric acid. Yet, when the acidity is neutralized, alfalfa and soybean plants develop root nodules typical of symbiotic nitrogen fixation with *Rhizobium* species possibly living in the pyritic material. When split open, these nodules exhibited the pinkish color of leghemoglobin, a protein in the nodule protecting the active nitrogen-fixing enzyme nitrogenase against the toxic effects of oxygen. Although we have not yet obtained direct evidence of nitrogenase activity in these nodules (reduction of acetylene to ethylene, for example), these findings suggested the possibility that nitrogen fixation was taking place in this hostile, non-soil material. This immediately raises the possibility that free-living anaerobic bacteria which fix atmospheric nitrogen on Earth, could do the same on Mars. The Martian atmosphere includes 2.7 % N_2 and 0.13% O_2 [1] -- if N-fixing anaerobes can adapt or be engineered to thrive in Martian "soil", one can postulate an eventual build up of organic nitrogen for subsequent use by other forms of life. Anaerobic photosynthetic bacteria that fix atmospheric nitrogen might, ideally, also build up oxygen in the Martian atmosphere, but the intense UV radiation reaching the Martian surface would preclude survival outside of a light-transparent shield. Sulfate-reducing bacteria such as *Desulfovibrio*, living beneath the surface with possible access to water adsorbed on fine particles, seem more promising in this regard. Free-living anaerobic diazotrophs on Earth include *Archaeoglobus* [2], the bacillaceae *Clostridium, Desulfatomaculum*, and *Desulfovibrio* [3] and the photosynthetic bacteria *Thiorhodaceae, Chlorobacteriaceae,* and *Athiorhodaceae* [4].

N_2-fixing organisms on Earth, whether free-living or symbiotic, have a common enzyme, nitrogenase, that mediates the following reaction:

$$N_2 + 8e^- + 8H^+ + nATP \Rightarrow 2NH_3 + nADP + nP_i$$

Splitting of the N_2 molecule is an energy-intensive process; 8 to 16 moles of ATP are required to fix 1 mole of N2. This value is not easy to determine because the partitioning of electrons between the two electron acceptors H^+ and N_2 depend on conditions such as ATP concentration, pH, substrate and substrate concentration. The electron donor in many of the systems studied is ferredoxin; where iron is deficient, flavodoxin has been found to substitute. Nitrogenase is a two-protein enzyme consisting of an Fe fraction and an FeMo fraction. The initial steps in the action of nitrogenase consist of the reduction of the Fe-protein, activation of the Fe-protein by Mg-ATP, followed by electron transfer between the nitrogenase proteins [5]. Under some conditions, V can substitute for Mo. Thus for starters, the N_2-fixing sulfate reducers require Fe, Mo, Mg, and an oxidant (sulfate or sulfite on Earth), N_2 in the atmosphere, and the absence of oxygen.

Elemental analyses of the Martian surface indicate an iron concentration (as Fe_2O_3) of 18 mass % and Mg as MgO of 8

mass % [1]; molybdenum and vanadium are possibly present, estimated to be about 1.7 ppm and 162 ppm, respectively [6], within the range of their occurrence in terrestrial soils. Sulfur is present at about 5 mass % (expressed as SO_3) in the "soil" from Pathfinder data [1]. Sulfite reduction is more thermodynamically favorable than sulfate reduction. In fact, reduction of sulfate by sulfate-reducing bacteria will not occur without initial activation by ATP and the formation of the intermediate adenylyl sulfatase [5]. Peroxides (whose presence in the Martian surface is inferred from interpretation of the Viking lander life-detection experiments) may serve as oxidants, albeit rather strong ones. These conditions, and effects on N_2-fixation can be tested experimentally in laboratory microcosms.

Another crucial component for survival of anaerobes is a carbon source. For *Desulfovibrio* and other N-fixing microorganisms, organic acids (e.g., malate, succinate, pyruvate, and lactate) and amino acids serve the purpose on Earth. On Mars, however, atmospheric CO_2 is the only abundant source of carbon known to be present (about 95% of its atmosphere). There is conflicting evidence that at least one species of *Desulfovibrio* could use CO_2 as a carbon source, but this result has more recently been attributed to mixotrophy, a coupled reaction [7]. Here, again, is an avenue for experimentation.

Peroxides in the Martian soil, intense UV radiation, extreme cold, and the absence of liquid water bode ill for the survival and evolution of Earth-like organisms on Mars. Yet, even on Earth we find microorganisms in the most unlikely places: in the core of a nuclear reactor, in a concentrated sulfuric acid copper solution, in thermal springs, in vents of volcanoes, and in Antarctica. Study of the physiology and biochemistry of anaerobic microorganisms, particularly the sulfate reducers, in a simulated Martian environment can demonstrate whether such life, or genetically engineered versions thereof, could survive and grow on Mars. Nitrogen-fixers on Earth have evolved several methods for protecting the enzyme nitrogenase against toxic oxygen: development of internal membranes, incorporation into plant nodules, formation of heterocysts, utilization of oxygen scavengers and reductants, and buffers such as leghemoglobin. On Mars, where O_2 is essentially absent, the N_2-fixers may find Heaven.

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A Remote Sensing/Geographic Information Systems Approach in the Selection of Mars Sites of Biological Interest

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The search for extinct or extant life on Mars is the search for past or present liquid water, respectively. There are numerous signs of past liquid water on Mars in the form of dry river valleys, paleolakes, and their associated flow and sediment patterns. While some of these features are recent (Amazonian, 1.8 billion years ago to present), there is no evidence that any are currently flowing. Liquid water on the surface would only be possible at those sites with sufficiently high temperatures and pressure. The key to the selection of sites on Mars to search for evidence of life is the search for the presence of water.

An approach to this problem is the use of remotely sensed data incorporated in a geographic information system (GIS). A GIS is a computer-based system capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e., data identified according to their locations. In planetary studies these data are acquired from remote sensing (RS) platforms (orbiters). These data are co-registered layers and, through the use of GIS analysis functions, areas on these layers can be selected as a function of the information desired. Our work used existing data layers from the Viking and Mars Global Surveyor missions to determine where water could be possible in liquid form on the Martian surface, based on the phase diagram for water.

Mars has water as ice in the polar caps and vapor in the atmosphere. The atmosphere often contains enough water to be saturated at nighttime temperatures. Frost was observed on the ground at the Viking 2 Lander site at 48°N and presumably forms at other high latitude sites as well. Water as liquid on the surface of Mars has not been observed and theoretical considerations suggest liquid water would not form on the surface due to low pressures and temperatures (Paige and Ingersoll, 1985). However, the pressures at the Viking sites (Tillman, et al., 1993) were always above the triple point of liquid water (6.1 mbar) and surface temperatures on Mars have been observed to rise above freezing (Keiffer et al., 1977). Thus, it is expected that pressure and temperature combinations exist on Mars what would allow liquid water. A map of such sites might reveal locations of the most recent liquid water activity or sites of possible transient liquid formation at the present epoch.

We have determined the locations and periods on Mars in which the pressure and temperature conditions are thermodynamically consistent with liquid water. The pressure at each location throughout the Martian orbit was determined from the Viking 2 Lander pressure record and extrapolated to other locations using the MOLA topographic data assuming hydrostatic equilibrium. Such analysis does not indicate that liquid water would be present at these sites but may indicate that such sites are locations of interest in terms of possible geochemical and biological activity of liquid water. Improved topography, atmospheric, surface composition, and other data from future Mars missions may provide better, more refined data layers that could be used to improve the RS/GIS analysis. This analysis could be used to guide site selection for increasingly finer-scale exploration and analysis on Mars.

DEEP INTERNAL STRUCTURE OF MARS AND THE GEOPHYSICAL PACKAGE OF NETLANDER.

P.Lognonné[1], D.Giardini[2], B.Banerdt[3], and the NL-SEIS team, V.Dehant[4], J.P.Barriot[5], and the NEIGE team, G.Musmann[6], M. Menvielle[7], and the MAGNET team. [1]IPGP, 4 Avenue de Neptune, 94100 Saint Maur des Fossés Cedex, France, lognonne@ipgp.jussieu.fr, [2] ETH, Zurich, Switzerland, [3] JPL, Pasadena, USA, [4] ORB, Bruxelles, Belgium, [5] GRGS, Toulouse, France, [6] TUBS-IMG, Braunschweig, Germany, [7] CETP, Saint Maur des Fossés, France.

Introduction: Our present understanding of the interior structure of Mars is mostly based on the interpretation of gravity and rotation data, the chemistry of the SNC meteoroids, and a comparison with the much better–known interior structure of the Earth. However geophysical information from previous missions have been insufficient to determine the deep internal structure of the planet. Therefore the state and size of the core and the depth and type of mantle discontinuities are unknown. Most previous seismic experiments have indeed failed, either due to a launch failure (as for the Optimism seismometer [1] onboard the small surface stations of Mars 96) or after failure on Mars (as for the Viking 1 seismometer). The remaining Viking 2 seismometer [2] did not produce a convincing marsquake detection, basically due to too strong wind sensitivity and too low resolution in the teleseismic frequency band. After almost a decade of continuous activity and proposals (ESA Marsnet, NASA Mesur, and ESA-NASA InterMarsnet) the first network mission to Mars, NetLander (NL), is expected to be launched between 2005 and 2007 [3]. One of the main scientific objectives of this 4-lander network mission will be the determination of the internal structure of the planet using a geophysical package. This package will have a seismometer, a magnetometer and a geodetic experiment, allowing a complementary approach that will yield many new constraints on the mineralogy and temperature of the mantle and core of the planet.

The core: The size, mineralogy and thermal state of the ***core*** is a crucial parameter for understanding a planet's accretion and internal structure. Assuming that the Martian core has a near adiabatic temperature gradient, it will be possible to model the core with very few parameters. If the core is liquid, such parameters will be the ***density***, the ***adiabatic bulk modulus***, the core-mantle boundary ***radius*** and ***temperature*** (the shear modulus being by definition zero for a liquid core). Other parameters, such as the partial derivatives of the density and adiabatic modulus with respect to temperature and pressure can be found with high-pressure laboratory experiments for candidate core mineralogies. Therefore, the determination of the mineralogy and temperature of the core is essentially equivalent to the determination of the 4 independent parameters described above and will be performed by the seismometer and the geodesy experiment.

The Mantle: One of the main goals will be the determination of the location of the main mantle discontinuities and the estimation of the temperature profile in the mantle. The shape of thediscontinuites will provide information on the iron content, which smoothes out the discontinuities over a thickness of one to two hundred kilometers [12]: such smoothing will be resolved by the seismic velocity model.

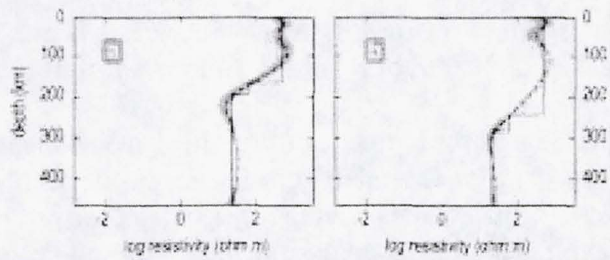

Figure 1: Figure for resistivity profile, after [10a]. The solid line shows the input model. The shaded area shows the recovered model. Simulations take network geometry and noise into account, for. a lithosphere thermal thickness of 200 km (a) and 300 km (b) respectively

The electrical resistivity a complementary source of information. It varies greatly with respect to thermodynamic conditions such as temperature,the percentage of conductive fluids within the solid matrix (molten rock, water-rich fluids) and the thickness of the lithosphere. Electromagnetic soundings will thus determine the thickness of the cold resistive lithosphere *[Figure 1],* and the presence (or absence) of partial melting at the base of the Mars lithosphere.

The NL Seismometer: This has a 2 kg mass allocation and consists of a 2 axis Very-Broad-Band seismometer, a 3+1 axis Short Period Broad Band seismometer and various environmental sensors. Sensitivity is better than 5 10^{-10} $ms^2/Hz^{1/2}$ in the band 1 mHz-1Hz and better than 5 10^{-9} $ms^2/Hz^{1/2}$ in the band 1Hz-50Hz. The seismometer science objective is the determination of the mean values of the shear and bulk elastic moduli and seismic attenuation as a function of depth through the recording of seismic and tidal data. These seismic data will consist of the recording of the natural quakes of the planet, whose occurrence frequency was estimated from surface fault observations [4] and from theoretical estimates of the thermo-elastic cooling of the lithosphere [5].

The detection zone of P and S waves for an example network configuration shows that the detection efficiency is very high in the Tharsis area, where small quakes of seismic moment of 10^{14} Nm might be detected *[Figure 2].* Both diffraction and attenuation, the latter extrapolated from the Phobos' secular acceleration measurement by [6], are taken into account. The experiment will also search for continuous seismic and tidal signals. These signals are associated to two continuous sources. The first will be the tide of the small Martian satellite, Phobos, A detailed discussion of the sensitivity of the signal with respect to structure are given in [8]. The second source, in the frequency band of 0.1-10 mHz, is the atmospheric turbulence. As shown by [9], such excitation processes on Mars might be almost as strong as those observed on the Earth. More details on the NetLander seismic experiment can be found in [10b].

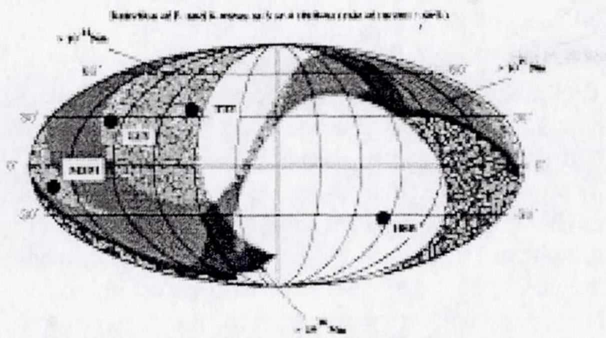

Figure 2: Detection area for Marsquakes. See details in [7].

NEIGE and Geodesy: The NEIGE experiment (see details in [10,11]), will make it possible to answer the question of whether the ***core*** is liquid or solid, as well as yielding other detailed information on Mars' interior by an improved measurement of the precession rate. It will use the NL telecom system, with 0.280 Kg mass allocation for specific components. NEIGE will also measure variations in the length of day, and therefore constrain mass exchange between the polar caps and the atmosphere. The size and state of the core will be determined by accurate measurements of Mars' ***nutation***. In particular, the nutation could be influenced by a resonance effect between the free nutation of a liquid core (FCN) and the nutation driven by the Sun with frequencies at multiples of the orbital frequency [*See Figure 3*]. The FCN observation will also directly lead to the determination of the CMB density jump. Improvement by a factor of 2.5 to 5 of the moment of inertia provided by NEIGE will reduce the present error to a level useful for real constraints in the core temperature and mineralogy.

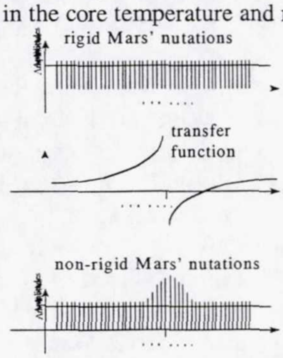

Figure 3: Schematic representation of the effect of the FCN resonance on the forced nutations.

MAGNET: The Magnetic Sounding experiment is composed of a network of identical triaxial subminiature fluxgate magnetometers, with a resolution of 0.025 nT and a mass allocation of 0.235 Kg (see details in [10c]). The attitude of the vector components of each triaxial fluxgate sensors will be known with an absolute accuracy of few tenths of a degree in both vertical and horizontal directions. The impedance of the internal structure will be deduced from the ratio of the vertical component of the magnetic field and the horizontal gradients of its horizontal component. With the simultaneous recordings from three or more stations available, the impedance will be estimated from the frequency-wave vector spectrum of the electromagnetic field using a high-resolution method developed by [10d]

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PRECISION NAVIGATION FOR A MARS AIRPLANE. James W. Lowrie, SAIC Center for Intelligent Systems, 8100 Shaffer Parkway, Suite 100, Littleton, CO 80127, e-mail: jlowrie@cis.saic.

Introduction: The rough Martian terrain significantly impedes high speed travel by wheeled vehicles and much of it is simply inaccessible given the capability of typical rover designs. Airplanes however, have much greater range and can provide access to scientifically interesting terrain that is inaccessible to landers and rovers. Moreover, they can provide coverage of a large portion of the surface and return high resolution images and science data not practical from orbiting spacecraft. Precise navigation on Earth requires a constellation of satellites such as GPS or a network of precisely located and calibrated ground beacons, an approach that is impractical for Mars exploration in the near future. In order to realize the benefits of airplane exploration on Mars, a precision navigation system is required. Such a system also provides a high degree of autonomous capability because it enables:

- Accurate overflight of specifically targeted sites.
- Hazard avoidance in low altitude flight.
- The collection of "focused" science data which reduces overall data volume and supports an optimized data return strategy
- Accurate spatial and temporal correlation of acquired science data with orbiter observations.
- A geodetically referenced site survey capability.
- A soft landing capability by providing in-flight landing site selection and terminal guidance.
- Return to a base station following flight.
- Precise placement of science probes and future navigation beacons.

SAIC's Center for Intelligent Systems (SAIC-CIS) leverages on experience from unmanned vehicle research to propose a concept for an intelligent landmark navigation system that relies on autonomous real-time recognition of visible surface features during flight

Technical Approach: Our concept as described herein, assumes an independently deployed system that doesn't rely on a lander spacecraft for delivery to Mars because it is the most stressing case for a navigation system. Upon entry into the Martian atmosphere, an airplane will initially descend through the atmosphere using an aeroshell / parachute deceleration system. After deceleration, the airplane will separate from the aeroshell and perform a pull-up maneuver to achieve level flight. The autonomous navigation system will then allow the airplane to follow a precise path relative to the planet's surface. Our technical approach relies on a mixture of image processing techniques to resolve both altitude and navigation position in a local coordinate frame.

The navigation system will process images from a primary imaging sensor to determine altitude and recognize landmarks. This data will be filtered with measurements from a barometric altimeter, inertial measurement unit (IMU) and air speed indicator to generate an airplane navigation state. These elements duplicate the functionality of a GPS receiver on terrestrial vehicles. Each of the major navigation elements is further discussed in the following sections.

Altitude Determination – A single camera on a mobile platform provides stereo vision by imaging the same region from two different positions. The primary science camera can thus determine altitude, which reduces cost and complexity by eliminating the need for a radar altimeter. There are three stages to the altitude determination process: algorithm initialization, initial altitude estimate, and ongoing updates. During algorithm initialization, the system acquires a first video frame and extracts high contrast features from the predicted overlapping region. The feature extraction process is repeated in the second image and a stereo correspondence operator applied. Constant operating conditions between frames, such as sun angle and illumination, allows for intensity correlation to establish correspondence at a 1 Hz rate. The resulting disparity estimates for the subimage are condensed into a single range estimate. The geometry in this configuration provides a range resolution on the order of +/- 10 meters to maintain a 2000-meter airplane altitude.

Landmark Tracking - The large initial uncertainty and limited airplane flight time make it necessary to refine the airplane position quickly to conserve resources and achieve an optimal flight path. Accurate vehicle position is obtained by correlating camera images obtained on the airplane with *a priori* geo-

detically referenced image data acquired from the Mars Surveyor Orbiter. This is known as landmark based position estimation.

The first position estimation is the most critical, because it represents the largest uncertainty and search area size, thereby imposing the most stringent requirements on the flight processor. Once the initial estimate is determined, the location of the next observable landmark can be predicted. The subsequent correlation-based position refinements are simplified because the improved navigation estimate provides knowledge of what landmark to look for. With a decreased search area, the correlation can work at higher resolutions producing more accurate position estimations. Our multi-resolution, correlation-based landmark position estimator will refine vehicle position to within 10 meters.

Our initial algorithm consists of a pre-flight component and runtime component. The pre-flight element uses existing Mars Surveyor images corresponding to the entry ellipse for generation of the *a priori* landmark chips. An interest operator is applied over the data set to extract key features and reduce volume. A set of image chips representing candidate landmark locations is built around areas of high scene activity. The runtime element begins during flight with the acquisition of images at regular intervals of approximately 3 seconds. The acquired image is rectified to match pixel resolution with the prestored reference chips using the altitude estimate from the navigation filter. The same interest operator will then be applied to the camera image over multiple resolutions and a list of image chips around areas of high scene activity is generated. This set of image chips represents the locations in the image to perform a correlation operation. Each chip in the acquired image will be correlated to all of the prestored chips and the maximal responding pair provides an update vector for the Kalman filter. A preliminary analysis performed using Mars Global Surveyor images indicates the processing time for this correlation is on the order of 1 second on a 650MHz Pentium III processor equating to 4 seconds on JPL's X2000 processor. Table 1 highlights our approach to the landmark navigation problem.

Navigation Filter – Because noise perturbations negatively affect the data being generated by each of the sensor subsystems, a navigation filter is needed to produce robust, accurate position estimates. A Kalman filter will be used to provide optimal estimates of the Airplane's state (position and orientation) by combining the Airplane's equations of motion with the IMU's data into its process update, and using the landmark tracking data as the basis for its measurement updates. We have implemented a preliminary filter and the along-track and cross-track errors were calculated for representative sensor noise profiles in a typical Mars environment, and subsequently combined into a circular error plot. The results show that the initial (asymmetric) error of 20 kilometers by 5 kilometers quickly reduced down to less than the target minimum error of 10 meters.

Key Technical Issues	Technical Approach
Large initial uncertainty drives large correlation requirements	Multi resolution approach reduces data volume Correlation of individual "chips" dramatically reduces the computational burden over the area based correlation approaches Interest operators limit correlation to high interest "chips" Interest operators reduce the bits required to represent a pixel
Limited throughput	Approach is compatible with the X2000 processor
Limited memory	Interest operators reduce the bits required to represent a landmark thereby reducing the associated memory requirements
Landmarks in the error ellipse must be matched at the camera frame rate to assure initial reference	Multi resolution approach uses lowest resolution for initial match to minimize throughput requirements Subsequent matches are performed at higher resolution and yield higher accuracy measurements

Table 1 - Multi-Resolution Landmark Tracking is Feasible with the X2000 Computer

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COOPERATIVE ROBOTICS AND THE SEARCH FOR EXTRATERRESTRIAL LIFE.

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Introduction: If we think tenuous abodes of life may be hiding in remote extraterrestrial environmental niches, and if we want to assess the biological status of a given locale or entire planet before sending humans (perhaps because of contamination concerns or other motivations) then we face the challenge of robotically exploring a large space efficiently and in enough detail to have confidence in our assessment of the biological status of the environment in question. On our present schedule of perhaps two or so missions per opportunity, we will likely need a different exploratory approach than singular stationary landers or singular rover missions or sample return, because there appear to be fundamental limitations in these mission profiles to obtain the many samples we will likely need if we want to have confidence in assessing the biological status of an environment in which life could be hiding in remote environmental niches. Singular rover missions can potentially accommodate sampling over a fairly large area, but are still limited by range and can be a single point of failure. More importantly, such mission profiles have limited payload capabilities which are unlikely to meet the demanding requirements of life-detection. Sample return has the advantage of allowing sophisticated analysis of the sample, but also has the severe limitations associated with only being able to bring back a few samples.

This presentation will suggest two cooperative robotic approaches for exploration that have the potential to overcome these difficulties and facilitate efficient and thorough life-detecting exploration of a large space. Given the two premises state above, it appears at least two fundamental challenges have to be met simultaneously: coverage of a large space and bringing to bear a sophisticated suite of detection and experimental payloads on any specific location in order to address a major challenge in looking for extraterrestrial life: namely, executing a wide variety of detection scenarios and in situ experiments in order to gather the required data for a confident assessment that life has been detected and to, more generally, cover a wide range of extraterrestrial life possibilities. Cooperative robotics lends itself to this kind of problem because cooperation among the combined capabilities of a variety of simple single function agents can give rise to fairly complex task execution such as the search for and detection of extraterrestrial life.

Shot-Gun Cooperative Robotics: Specifically, a kind of *cooperative robotics shot-gun approach* [1] in the form of tens to hundreds or more small robots, each with a singular life-detection related capability such as detection of water and organics (perhaps even nucleic acids, amino acids and associated chirality, etc.) or such as metabolism measurement experiments, epiflourescence microscopy, molecular sequencing, culturing, sub-surface boring payloads, imaging capabilities, etc. could cover much area and work together by communicating results to the rest of the "swarm" which could then focus on a particular location where a positive result was found.

Mission Scenario Example: An over-simplified search and detection scenario might be something like: first send many small water detection robots, including subsurface boring moles, to a promising area. If water is detected by any one robot, confirm with another robot, and signal to other robots (which could be stored nearby or in orbit, or already deployed nearby, etc.) that have the functionality for the next step which might be detection and measurement of organics. If a promising result is reported, perhaps a metabolism based experiment would be required next, followed by an imaging based robot, and then perhaps more sophisticated functionality such as molecular sequencing or culturing.

In general, this approach can been seen as a kind of biologically inspired exploration methodology, perhaps a form of "swarm intelligence" [2]. The benefit of this kind of approach is that large areas can be covered with diverse detection and experimental techniques which increase the chance of detecting life, and comprehensive data can be obtained in an efficient manner during just one mission opportunity.

. **Cooperative Family Robotics:** A second form of cooperative robotics might be characterized as *cooperative family robotics* where a larger parent rover carries smaller rovers with additional specialized functionality to be deployed as required by the higher level analysis of the more mobile larger rover. A system like this could be large or small. If a larger size were feasible, we'd want to consider the possibility of developing a walk-roll and maybe even hop capability perhaps by designing lockable wheels that can act as feet for walking (e.g. to navigating difficult terrain) and allow for crouching and perhaps hopping, as well as covering large distances by unlocking the wheels for rolling. The primary advantages of this approach are that specialized functions can be selectively deployed in real-time and that the parent rover can act as a central coordinating agent as well as an infrastructural support element for power recharging of the smaller rovers and more sophisticated forms of navigation, drilling, communication, etc.

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Pgs 2

MITIGATING ADVERSE EFFECTS OF A HUMAN MISSION ON POSSIBLE MARTIAN INDIGENOUS ECOSYSTEMS.

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Introduction: Although human beings are, by most standards, the most capable agents to search for and detect extraterrestrial life, we are also potentially the most harmful. While there has been substantial work regarding forward contamination with respect to robotic missions, the issue of potential adverse effects on possible indigenous Martian ecosystems, such as biological contamination, due to a human mission has remained relatively unexplored and may require our attention now as this presentation will try to demonstrate by exploring some of the relevant scientific questions, mission planning challenges, and policy issues. An informal, high-level mission planning decision tree will be discussed and is included as the next page of this abstract [1].

Some of the questions to be considered are: To what extent could contamination due to a human presence compromise possible indigenous life forms? To what extent can we control contamination? For example, will it be local or global? What are the criteria for assessing the biological status of Mars, both regionally and globally? For example, can we adequately extrapolate from a few strategic missions such as sample return missions? What should our policies be regarding our mission planning and possible interaction with what are likely to be microbial forms of extraterrestrial life?

Central to the science and mission planning issues is the role and applicability of terrestrial analogs, such as Lake Vostok for assessing drilling issues [2], and modeling techniques. Central to many of the policy aspects are scientific value, international law, public concern, and ethics. Exploring this overall issue responsibly requires an examination of all these aspects and how they interrelate [3, 4, 5].

References:

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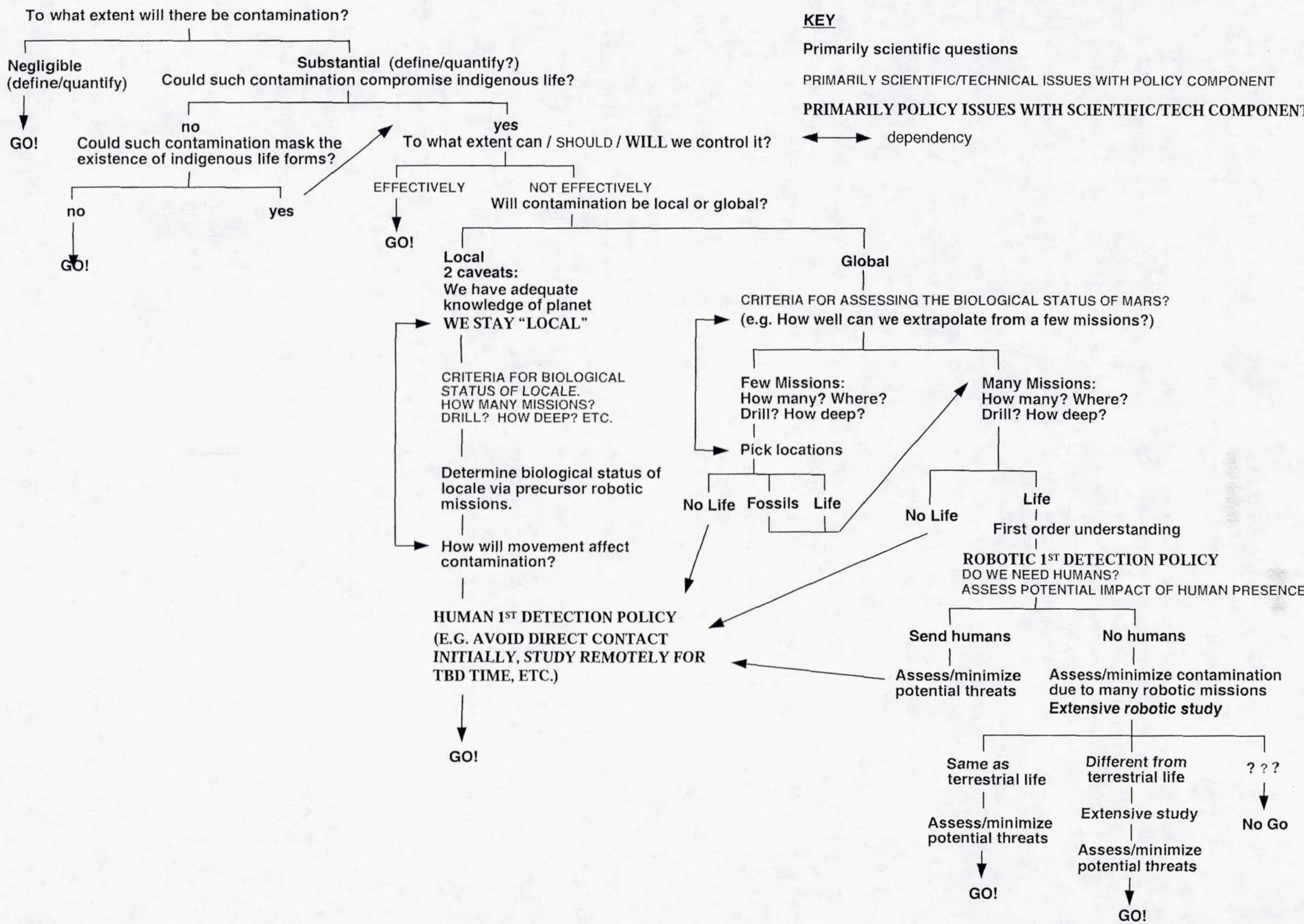
Mission Planning Decision Tree for Mitigating Adverse Effects to Possible Indigenous Martian Ecosystems due to a Human Mission



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MARS GREENHOUSE EXPERIMENT MODULE, AN EXPERIMENT TO GROW FLOWERS ON MARS. T. K. MacCallum[1], J.E. Poynter[1], and C. P. McKay[2], [1] Paragon Space Development Corp. 810 E. 47th St, #104, Tucson, AZ 85713; [2] NASA Ames Research Center, Mail Stop 245-3, Moffett Field, CA 94035.

Introduction: NASA has entered a new phase of in-depth exploration of the planets where robotic exploration of the Solar System is focusing on in-situ missions that pave the way for human exploration. Creating a human presence on Mars will require specialized knowledge and experience concerning the Martian environment and validated technologies that will provide life-supporting consumables. An understanding of the response of terrestrial organisms to the Martian environment with respect to potential deleterious effects on crew health and changes to biological processes will be paramount.

In response to these challenges an innovative self-contained flight experiment is proposed, which is designed to assess the biocompatibility of the Martian environment by germinating seeds and following their growth through to flowering. The experiment, dubbed Mars Greenhouse Experiment Module (Mars GEM), will be accomplished in a sealed pressurized growth chamber or "Mars Greenhouse". Seeds will be grown in Martian soil and the Mars Greenhouse will provide ultraviolet-radiation protected, thermal-controlled environment for plant growth that actively controls the CO2 (required nutrient) and O2 (generated by the plants) levels in the chamber.

The simple, but visually dramatic demonstration of the potential to grow a plant in a man-made environment on the surface of Mars should establish a strong connection between current robotic missions and future human habitation on Mars.

The Objectives and Significant Aspects: The experimental goal is to determine the biocompatibility of the Martian environment such as the atmosphere and regolith. This is to be accomplished by studying the stress sustained by an Earth organism (an angiosperm) grown in Martian soil and possibly Martian CO2 and water during germination, growth and production of flowers. Such an experiment will determine if exposure has deleterious effects or results in fundamental changes to biological processes. A second objective is to ignite public interest in the exploration and possible future colonization of Mars and elsewhere in the solar system.

NASA has a long tradition of flying technology demonstration missions. Once a technology has been tested on Earth it is important that we gain technical and psychological reassurance by demonstrating that something works on Mars. Pathfinder was such a mission. A module capable of growing plants from seed is a biological demonstration mission similar to plans to test physical/chemical oxygen production from atmospheric carbon dioxide on Mars.

There are many reasons to send flowers to Mars. It would be highly symbolic. These plants would be the first organisms from Earth to grow, live and die on another world. They would be true biological pioneers, an important step for life from Earth as it begins its expansion beyond the planet of origin. More practically, a plant growth module would test the toxicity of the Martian environment in a very direct way. If Martian CO2 and water are used, the experiment would demonstrate the use of Martian atmosphere components in a greenhouse. These are essential steps toward a full-scale greenhouse to support a human base. The growth of a plant in the Martian environment would help alleviate concerns about dangerously contaminating the Earth by the return of Martian samples by showing that the soil and atmosphere are compatible with life. In all these respects a plant growth module would be a first biological precursor to human exploration of another planet.

The Technical Feasibility: Due to planetary protection requirements and the inherent constraints imposed by a pressurized growth chamber, the plant life support system must be completely materially closed. Paragon Space Development Corporation has performed design studies including plant requirement definition, thermal analysis, regolith collection and dissemination, nutrient and water delivery, seed delivery, CO2 and O2 measurement and control, and pressure control. The chamber and subsystems have undergone preliminary design studies and all parameters (mass, size, electrical power, data etc.) can be met using a growth chamber that can be supported as an instrument package on a Mars-01 type lander. The chamber weighs approximately 3.5 Kg, is 17 cm wide by 19 cm high by 25 cm long, and uses less than 16 W-hrs during operational hours. No power is required during the darkness of night.

Planetary protection issues have been studied in depth to ensure that designs meet all criteria for eliminating the risk of contamination of the Martian surface with Earth borne life. The planetary protection guidelines do not explicitly prevent the controlled transport of biological materials to Mars and the use of biological materials in controlled experiments aboard spacecraft. The seeds of the plants would be treated in such a way as to minimize the risk of transport of bacteria. In addition, the sealed chamber is sterilized prior to transportation and treated with high levels of antibiotics and antifungal agents during the experiment. At the completion of the experiment the entire chamber is sterilized to ensure that no microbial life has survived and that all bacteria have been eradicated. Growing a flower on Mars would not contaminate the planet or compromise any future scientific study of the planet.

The plant proposed for the experiment is *Arabidopsis thaliana,* which is used extensively in laboratory gene expression and physiology studies. Thus a large body of knowledge exists with regards to its requirements and propa-

gation. Phenotypes are available that have low light intensity requirements, dwarf plant sizes, short inflorescence, with 45 days to flowering and senescence. The plant will be selected and possibly genetically manipulated to tolerate elevated levels of free-radicals expected in Martian soil and thus can serve as a biosensor for measuring oxidative stress. Further genetic engineering can be performed using Green Fluorescing Protein whereby each plant can indicate the presence or absence of specific stress factors such as toxic levels of metals, high salinity etc. The plants' growth and flowering would be monitored using the lander camera and a camera internal to the growth chamber.

The vessel has an antechamber with a door to the Martian atmosphere to allow the planting bed to be filled with Martian regolith. Once the exterior door is sealed the chamber is pressurized and the soil hydrated before being moved into the greenhouse. Current designs use only that portion of the atmosphere that enters the antechamber from the Martian atmosphere while the door is open. Further design studies need to be performed to determine whether all the CO_2 and water used in the experiment can be derived from the Martian atmosphere while conforming to the power and mass limitations of a mars lander.

The greenhouse is constructed with a combination of transparent aerogel and phase change material. A thermal model has been made which shows that the proposed method of heat storage and release maintains the temperature within requirements without the need for a powered heat source at night.

Through 6 years of in-depth work in the field of closed biological systems and biological systems made for space use, Paragon has developed innovative concepts for CO_2 and O_2 control. These systems allow for an entirely sealed growth chamber with small volume requirements, and reduce the amount of gases required for delivery to the plants from pressurized canisters. An atomic level model has been made that tracks the movements of carbon, hydrogen and oxygen within the system. The model demonstrates the need for daily release of CO_2 and nightly storage of CO_2 due to plant metabolic processes, which the Paragon system accomplishes with no moving parts and low energy requirements. No energy is required at night for O_2 storage.

Summary: For most of us life is the reason that Mars is interesting. We go to Mars to search for the possibility of life early in Martian history when that planet had water and to determine if Mars may be a home for life in the future.

The proposed Mars Green House Experiment Module is conceived to provide important scientific data and to validate exploration technology as a precursor to human missions. The experiment provides for an exceptional opportunity for public education and outreach. It is technically feasible and the maturity of design studies show that a Mars GEM could be used to send life to Mars on the next lander.

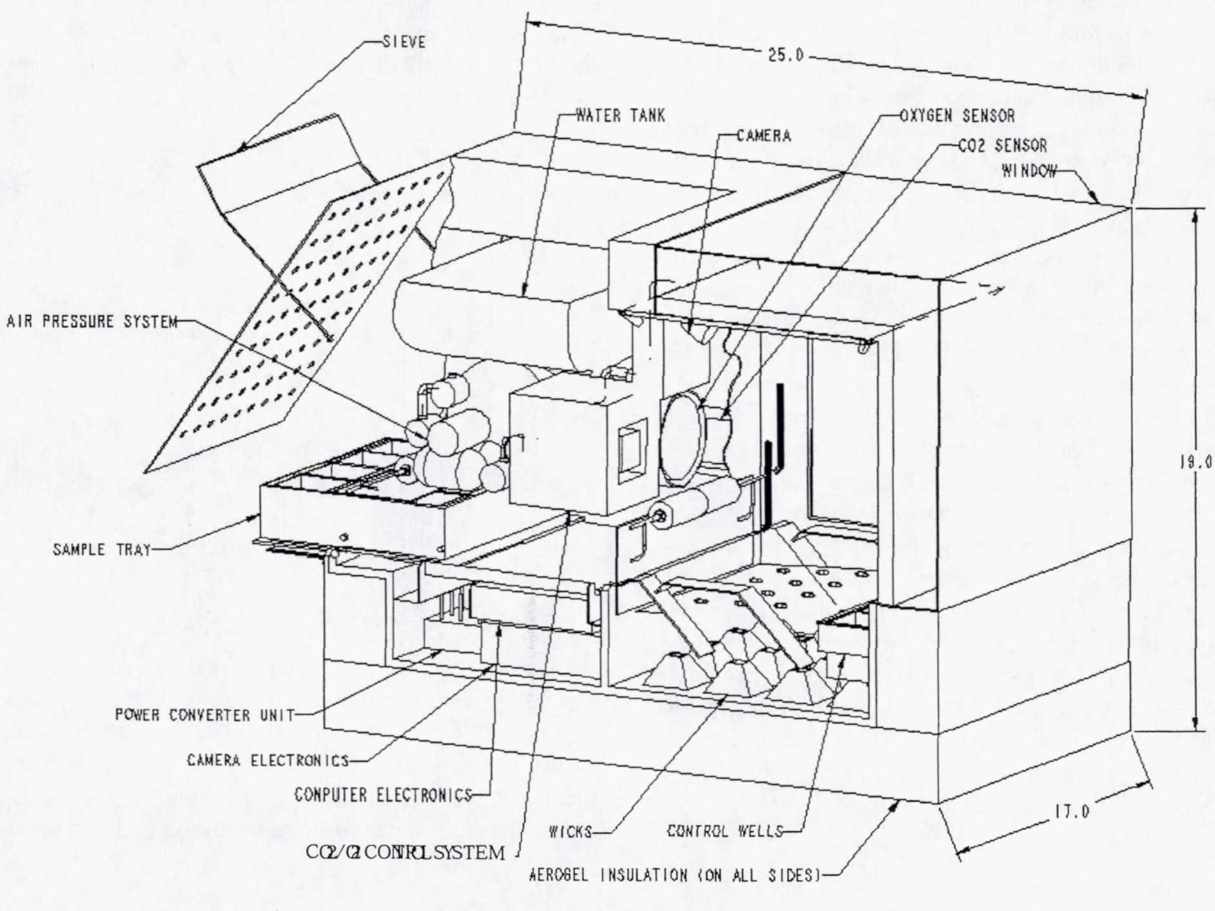

Figure 1. Mars GEM Design Concept

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MOLECULAR AND HIGHER PRECISION ISOTOPIC MEASUREMENTS OF THE MARS ATMOSPHERE AND SUBSURFACE VOLATILES. P. R. Mahaffy[1], S. K. Atreya[2], T. C. Owen[3], H. B. Niemann[1], J. Jones[4], and S. Gorevan[5], [1]Code 915, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA, [2]Department of Atmospheric, Oceanic and Space Sciences, University of Michigan, 2455 Hayward Street, Ann Arbor, MI 48109 USA, [3]University of Hawaii, Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822 USA, [4]Jet Propulsion Laboratory, M/S 157-507, 4800 Oak Grove Drive, Pasadena, CA 91109 USA, and [5]Honeybee Robotics 204 Elizabeth Street, New York, New York 10012 USA.

Introduction: In response to the question "what to do next" at Mars we explore the value of a **high precision insitu measurement of isotopic and trace gas constituents in the atmosphere combined with a similar analysis of gas extracted from near surface rocks and soils.** The scientific goals are to advance our understanding of the evolution of the Martian atmosphere and to search for fossils of past geochemical conditions. One element of this program that ties directly to the goals of the Astrobiology Program will be a sensitive search for simple or complex organic molecules contained in the atmosphere and in the solid phase. The broad chemical and isotopic analysis planned insures that a highly successful program will be carried out even if no organics are detected. We will demonstrate that the technology to carry out this program is presently in hand.

Scientific Goals: Three principal areas are addressed by the investigation proposed:

(1) precise isotopic composition of the well mixed atmosphere including all noble gases and common elements in different molecular reservoirs. The measurements will constrain models of the loss of a portion of the atmosphere to space and subsurface reservoirs. For example, the $^{36}Ar/^{38}Ar$ ratio was not well constrained by the Viking GCMS experiment. Precise measurements of all the krypton and xenon isotopes allow comparison with the trapped gas in the SNC meteorites and in material from future sample return missions.

(2) The isotopic and chemical composition of volatiles contained in rocks and subsurface clays and soils. These measurements will reveal the nature of these materials (for example, identify carbonates or sulfates from thermal degradation to CO_2 or SO_2), constrain the nature of the present atmosphere/surface exchange, and may reveal molecules chemically bound when the climate was substantially different.

(3) The search for trace species in the atmosphere and evolved from solids such as orgnics. For example, the present upper limit to the methane atmospheric abundance can be extended by several orders of magnitude by these measurements and a Viking-like search for complex organics carried out this time from well below the highly oxidized surface materials.

Measurement Requirements: These broad scientific objectives outlined give rise to stringent measurement requirements. Isotope ratios in trace (ppb) noble gas species must be measured to the per mille level. Chemical conversion of major species must be carried out isolate isotopic ratio differences in different molecular reservoirs. Trace atmospheric species present at the mixing ratios down to sub parts per billion must be analyzed.

Technology Status: Fortunately, the technology to meet these requirements presently exists as a result of development for recent planetary missions such as the Cassini Huygens GCMS [1] (in cruise), the Champollion ST4 comet nucleus lander (mission recently canceled) and development support from NASA for the Mars specific measurement issues. Under the ST4 development program, for example, a Sample Collection and Transport Mechanism (SATM) was developed and tested to penetrate either hard or soft materials to a depth of 1-2 meters and return a sample to a pyrolysis chamber for GCMS chemical analysis. The Huygens GCMS that will encounter Titan's atmosphere in 2004

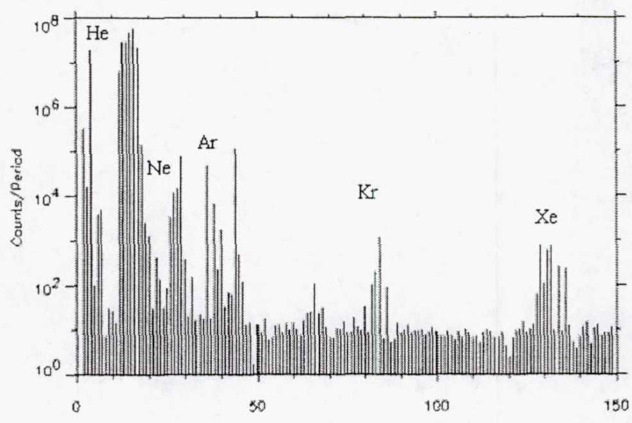

Figure 1 *Noble gas isotopes at Jupiter*

will carry out exactly this type of analysis using GCMS technology considerably advanced from the Viking era. The range of chemical analysis would require multiple subsurface samples and chemical and physical enrichment and reactive processing of atmospheric constituents to produce a gas suitable for introduction to either

MOLECULAR AND ISOTOPIC ANALYSIS: P. R. Mahaffy et al

the MS directly or to the inlet of the GCMS. The isotopic precision required has been demonstrated in the laboratory using flight like instrumentation. Heritage for this type of experiment also comes from the Galileo Probe mission. Detection of noble gas isotopes at Jupiter [2, 3] using the Probe Mass Spectrometer is illustrated in Figure 1. The effectiveness of the gas separation used at Jupiter is illustrated by this figure since each xenon isotope is present in the Jovian atmosphere at a sub ppb mixing ratio.

Example Mission Design: The preliminary definition of exactly such an experiment sized to the micromission carrier presently under study and soft landed on Mars by a Montgolfier balloon was recently carried out in a joint GSFC/JPL/Honeybee Robotics

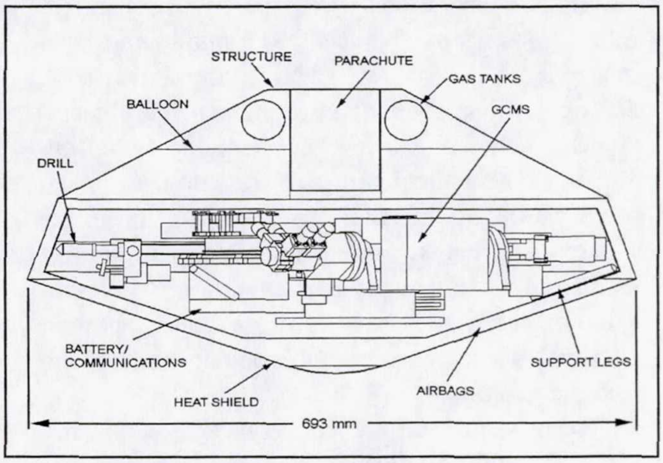

***Figure 2** An example of a small payload in the stowed configuration for delivery to the Martian surface.*

study [4, 5]. Figure 2 illustrates the configuration of a GCMS, based payload delivered to the surface of Mars by such a system. Although, the Montgolfier can deliver the payload with an arbitrarily low vertical velocity, the payload is dropped and protected by small airbags just above the surface to avoid damage due to a wind driven horizontal velocity. The stowed SATM (shown) rotates into a vertical position after deployment and can extend to more than twice its stowed length to penetrate more than one meter in this micromission delivered payload.

Enhancements to the Example Mission: The small payload delivered to the surface in this study contained the SATM, the GCMS, and a camera. It was designed to obtain atmospheric and subsurface samples only at the landing site. Enhancements to this concept could be enabled by moving outside of the constraints of the micromission delivery system to allow a considerably extended measurement lifetime and the option of roving to multiple sites across the surface. Particularly, interesting are the advanced rover techniques presently being prototyped by JPL that use inflatable tires to maximaze efficiency in traversing rocky terrain and covering large distances in a relatively short time period. An SUV-sized, 20-kg inflatable rover prototype has been developed [6] that can readily climb over 0.5 m rocks, thus enabling rapid transportation (~5 km/hr) over 99% of the Martian surface with relatively low mobility power requirements (< 20 watts). Together with advanced deep subsurface sampling technology under development by Honeybee Robotics a wide region search for subsurface water and organic species can be significantly advanced.

Conclusions: In spite of its negative result on organic molecules, the Viking lander mass spectrometer measurements in 1978 provided data that was the key to achieve the understanding that the origin of the SNC meteorites was most likely Martian. Similarly significant advances in our understanding of the evolutionary history of Mars are expected whenever we decide to finish the job that the Viking GCMS started. Priority should be given to now measuring with high precision of the isotopic composition of the Martian atmosphere and chemical analysis of gases evolved from samples collected well below the highly oxidized surface. Insitu measurements by surface landers can achieve these measurements and be carried out at a small fraction of the cost of a sample return mission. Such missions are logical precursors to these more ambitious sample return efforts.

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RETURNED SAMPLES: THE EXPECTATIONS AND IMPLICATIONS. G. Manhès, J. L. Birck and C. J. Allègre, Laboratoire de Géochimie et Cosmochimie, IPGP, 4 Place Jussieu, 75252 Paris Cedex 05, France (birck@ipgp.jussieu.fr).

Introduction: Before the exploration of Mars, the Apollo and Luna programs are the only example of a planetary invesgation including a sample return. The context is somewhat different but the scientific logic to get the best knowledge of a planet from the available remote instruments or returned sample, is broadly similar. The purpose of the present paper is to illustrate some constrains of the geological exploration of a planet. Although there has been 30 years that the fisrt moon samples were returned to the earth for study and that there will be around another ten years before the Mars sample return, there is still a number of measurement methods applied on lunar samples within terrestrial labs which have to day no equivalent counterpart in remote operated instruments. This does not mean that there was no progress but that despite the advances in automation and the power increase in computer process control, there are methods which require either large instruments because of the nature of physics or the presence of the human operator because of the complexity of the analytical procedures. This holds for a constant level of investigation capacity which of course is not the case as the evolution of laboratory instruments has also been tremendous over the last decades in mostly two directions: improvement of the potential of existing instruments and the introduction of new instrumentation concepts e.g. atomic force microscope or ICPMS. Adaptation of the instruments to unexpected properties of the sample is also much faster and efficient for the scientific return when samples are already on Earth.

Guidelines: Within the frame of the dominant objectives focused on life, climate and resources, time is an essential parameter. There is no way to describe the past and present processes within and on the surface of Mars without having a time scale. Major issues are also the identification of the planetary reservoirs and their evolution through time. This holds for the main geological units: core, mantle, crust but the fate and history of water is tightly connected to these. The time scale is established on measuring the formation ages of rocks and this can be achieved only on returned sample with high precision isotopic measurements on actual rock samples. The sample size depends on the conservation state of these chips or whatever cores but cm sized rocks at least for a number of them is a requirement. This can work on much smaller samples, depending on composition, but cannot be downscaled beyond limits because of the atomic nature of matter; thermodynamic statistics set the minimum number of atoms to be measured to reach the required level of precision. This leads to a miminum range in size from 10's of mg to 1gm.. Why is that so ? Dating is done with many complementary techniques, each with its own applicability based on the physico-chemical nature of the samples and its preservation. As martian samples are going to be different of what we know from meteorites and the moon and as some degree of alteration is present, it is absolutely necessary to cross check the ages obtained with several radiochronometers used in isotopic geology.

The essential difference between Moon samples and the future samples returned from Mars is sample availability. Typical Apollo samples sizes were in the kilogram range. Luna samples were somewhat smaller (~100g) but with less variability and they were less extensively investigated. Such amounts allowed to run the different experiments on separate splits of the sample and also to duplicate most of the experiements. On the MSR samples this will be no more possible. Expected amounts are in the gram range that is about three orders of magnitude less. Instruments and the skill of the experimentators has improved both in precision and in sensitivity but this does not compensate for this reduction. As stated hereabove downsizing the sample used in each experiment has its limits or will degrade the quality of the data relative to the possibilities of the instruments. The analytical procedures for isotopic work and also some of the trace element work also implies the destruction of the sample. Taking all this into account, the only processing strategy is to combine most if not all of the experiments into a

single integrated procedure which measures all elements from one aliquot of the starting sample. This has already been partly done in the past for example combined Rb-Sr and Sm-Nd measurement or combined measurements of the whole rare-earthes group but not at the global scale. This is now an absolute requirement and has to be prepared over the coming years. The implications are of two kinds: establishment of very reliable procedures and blank reduction.

Firstly the reliability should be high enough that duplication of measurement should not be neccessary. This has greatly been achieved already for the Moon samples, the only endeavour is to repeat this with the redesigned analytical scheme. Also the constraints in natural samples are variable from element to element and the highest requirements are on those which have to be measured with high precision and having low concentration. In the very same sample separates at least some of the other elements will be in sufficient amounts to do several repeats. The validity of the procedure has to be tested on actual samples the composition of which is close of what is expected to be returned from Mars. The terrestrial medium has such a variety of rocks that there should be no difficulty to find well documented equivalents. But the robustness of the methods can also be investigated for strongly different compositions as actual returned samples may be far from expectations and also to take into account the variability of the rocks if an "intelligent" sampling program can be performed.

Secondly integrated procedure imply either more complex preparation or separation chemistry with intrinsically higher procedural blanks when compared to simple parallel analysis. Bringing blanks to levels where they do not alterate the precision of the measurement naturally follows the testing process on actual samples. Every reagent or material in contact with the samples has to be inspected before entering into the analytical procedure. These inter-elemental cross-checks have also to be performed for every tracer added to the sample e.g. the enriched isotopes for the isotope dilution measurements. This is a time consuming process which may take a few years and in which almost all elements have to be followed closely.

Additional comments: Non destructive observations can normally be applied extensively without harm for future investigations. Nevertheless in most cases some preparation of the sample is involved like polishing or coating which actually destroys the samples for many other experiments. It means simply that the same experiment can be carried out several times on exactly the same sample. Real non destructive observations allowing almost all further experiments on the same sample are in fact seldom: X-Rray examination is one of the most harmless. The sampling itself is already part of this process as an experienced field geologist can give some parameters of their composition within a given context. This is also what is expected from in-situ experiments connected to an "intelligent" sampling strategy. Before going to the destructive experiments, samples will be characterized with non destrutive methods for mineralogy and petrography as well as for biological signature but this will also produce significant information on the chemistry of the samples. In taking these data into account together with the elements teh most difficult to measure, the management of the sample distribution among the different experiment can be even more closely trimmed to a minimum consumption.

The importance of bringing back rocks or rock chips has also to be emphasized to obtain reliable ages which are cross checked with several dating methods. Theses ages can not be obtained an wind blown dust. This dust represents a planetary average which may be biased by unknown sorting factors (size, hardness, density...).

With samples in the range of grams there are elements which can already not be measured optimally even when using the whole sample: Os is one example. If it happens that basalts from Mars are less radiogenic than terrestrial ones, higher precisions will be required and there will not be enough Os atoms in the sample to reach them. But this is a speculation for the time being.

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DREAM (DISPOSITIF DE RETOUR D'ÈCHANTILLON D'ATMOSPHÈRE MARTIENNE) : MARTIAN ATMOSPHERE SAMPLE RETURN. B. Marty[1], E. Chassefière[2], P. Agrinier[3], A. Jambon[3], M. Javoy[3], B. Lavielle[4], K. Marti[5], M. Moreira[6], D. Pinti[7], F. Robert[8], Y. Sano[9], P. Sarda[7]. [1]CRPG/CNRS 15 Rue Notre-Dame des Pauvres, BP 20, 54501 Vandoeuvre-lès-Nancy Cedex, France, bmarty@crpg.cnrs-nancy.fr, [2]Centre d'Etudes Terrestres et Planétaires, IPSL, Paris, [3]Laboratoire de Physico-chimie des Fluides Géologiques, Université P. et M. Curie and IPG Paris, [4]Laboratoire de Chimie Nucleaire Analytique et Bioenvironnementale, Centre d'Etudes Nucléaires de Bordeaux-Gradignan, [5]Department of Chemistry & Biochemistry, University of California, San Diego, [6]Laboratoire de Géo et Cosmochimie, IPG, Paris, [7]Groupe de Géochimie des Gaz Rares, Paris XI-Orsay, [8]Muséum National D'Histoire Naturelle, Paris, [9]Departement of Earth and Planetary Sciences, Hiroshima University.

Introduction: The elemental and isotopic composition of the Martian atmosphere are poorly known from the analyses of VIKING. The similarity between this composition and that of trapped gas inclusions in SNC meteorites led to the conclusion that SNC were from Mars and allowed scientists to refine estimates of Mars atmospheric composition. Due to the large uncertainties remaining on the elemental and isotopic compositions of C, O, N and noble gases, extremely important problems concerning the origin and evolution of the Martian hydrosphere and atmosphere as well as for the geodynamical evolution of Mars cannot be resolved with available measurements. Specifically, the following processes require a precise knowledge of the Martian atmospheric composition : Chemical and isotopic zoning in the solar nebula; Accretion processes; degassing of the planetary interior (catastrophic or/and continuous), contributions of chondritic and cometary material; solar wind input; atmospheric evolution (T. Tauri, thermal, sputtering, impact erosion). Geological features of the presence of liquid water and its present-day absence, the relative abundance of CO_2 and N_2, the relative abundances of noble gases, isotopic composition of hydrogen, nitrogen, argon and xenon are all puzzling features which would be explained in a comprehensive model.

Why do we need to retun an atmospheric sample in a separate container ? We propose to develop a Martian atmosphere sampling experiment which will allow the return to Earth's laboratories of well characterized atmospheric samples. These samples will permit the analysis of major and minor volatiles with high precision. Such precision, notably of the order of 1 % on Xe isotopes, is critically required to resolve important issues on the timing of Mars atmosphere-mantle interactions as well as on the irradiation history of Mars.

The return of Martian atmosphere samples does not substitute to an in-situ measurement but instead supplement it, both experiments having flaws and advantages. Among the advantages of an in-situ measurement (see the PALOMA project [1]), such experiment will allow to measure with reasonable accuracy atmospheric gases from an unlimited reservoir and through time (e.g. seasonal variations), whereas the laboratory measurement will permit specific investigations on key parameters for which analytical precision will be out of reach by a automated measurement. Notably, the twin experiments will allow to crosscheck the data. Finally, in case of failure of one of the two experiments, we expect to have nevertheless access to an atmospheric composition data set much better than available at present.

The low temperature release (< 200°C) of volatiles from Martian rock has now experimentally been observed (without introducing shock effects as expected in rock containers). Therefore, the exchange and mixing of rock gas and container atmosphere has to be expected. As the indigenous isotopic signatures differ dramatically from atmospheric gases, this would severely compromise the isotopic and elemental information on the evolution of volatiles. It may not only compromise, but invalidate the information.

Only small sample containers (2-3cc) are required for elemental analyses; these would provide unfractionated elemental data. Therefore, duplicate containers (and duplicate sampling on two missions) should be considered.

Heavy rare gases and also important minor molecular species which can be concentrated by low-T adsorption in adsorbers (which need to be tested and selected!) would increase the information content significantly. This is especially relevant for high precision isotopic work (e.g. Xe) and for species that are relevant for studies of exchange/loss mechanisms (H2O, N2). These samples obviously will require additional containers.

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The Next Generation MOD: A Microchip Amino Acid Analyzer for Detecting Extraterrestrial Life

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The MOD (Mars Organic Detector) instrument which has selected for the definition phase of the HEDS package on the 2005 Mars Explorer Program spacecraft is designed to simply detect the presence of amino acids in Martian surface samples at a sensitivity of a few parts per billion (ppb). An additional important aspect of amino acid analyses of Martian samples is identifying and quantifying which compounds are present, and also distinguishing those produced abiotically from those synthesized by either extinct or extant life. Amino acid homochirality provides an unambiguous way of distinguishing between abiotic vs. biotic origins (Bada and McDonald 1996). Proteins made up of mixed D- and L-amino acids would not likely have been efficient catalysts in early organisms because they could not fold into bioactive configurations such as the a-helix. However, enzymes made up of all D-amino acids function just as well as those made up of only L-amino acids, but the two enzymes use the opposite stereoisomeric substrates. There are no biochemical reasons why L-amino acids would be favored over D-amino acids. On Earth, the use of only L-amino acids in proteins by life is probably simply a matter of chance. We assume that if proteins and enzymes were a component of extinct or extant life on Mars, then amino acid homochirality would have been a requirement. However, the possibility that Martian life was (or is) based on D-amino acids would be equal to that based on L-amino acids. The detection of a non-racemic mixture of amino acids in a Martian sample would be strong evidence for the presence of an extinct or extant biota on Mars. The finding of an excess of D-amino acids would provide irrefutable evidence of unique Martian life that could not have been derived from seeding the planet with terrestrial life (or the seeding of the Earth with Martian life). In contrast, the presence of racemic amino acids, along with non-protein amino acids such as α-aminoisobutyric acid and isovaline, would be indicative of an abiotic origin, although we have to consider the possibility that the racemic amino acids were generated from the racemization of biotically produced amino acids (Bada and McDonald 1995).

A potential impediment to the search for life on Mars is the forward contamination of the planet with either terrestrial organisms, or more likely terrestrial biomolecules. This problem would be of great importance in assessments of whether there are any amino acids indigenous to Mars. Because of the distinctive L-enantiomer signature of amino acids associated with terrestrial life, chiral amino acid analyses can be used to monitor the level of forward contamination of Mars which occurs during the course of planetary exploration. This requires that amino acid analysis data be acquired as early as possible in the Mars exploration program in order to provide a useful baseline data set for comparison with future analyses. A long range monitoring program would be critical in assessing forward contamination during the eventual human exploration of Mars.

A relatively new technology which shows promise for spacecraft-based amino acid enantiomeric analysis is microchip-based capillary electrophoresis (µCE). With µCE, both the identity and enantiomeric composition of amino acids can be determined at sub-part-per-billion levels. The µCE based analyses are about an order of magnitude faster than analytical methods such as conventional CE and high performance liquid chromatography (HPLC). Such short analysis times are an inherent advantage for robotic *in situ* measurements carried out from a spacecraft. In addition, µCE has a detection limit more than three orders of magnitude better than conventional HPLC. Thus, proportionally smaller samples (~100 pl or 10^{-10} l) can be analyzed, another important advantage for *in situ* spacecraft based instruments.

Under a project funded by the Planetary Instrument Definition and Development Program (PIDDP), a µCE chip system has been used to explore the feasibility of using such devices to analyze for amino acid enantiomers in extraterrestrial samples (Hutt *et al.* 1999). The test system consisted of a folded electrophoresis channel (19.0 cm long x 150 mm wide x 20 mm deep) that was photolithographically fabricated in a 10 cm-diameter glass wafer sandwich, coupled to a laser-excited confocal fluorescence detection apparatus providing sub-attomole ($<10^{-18}$ mole) sensitivity. The µCE

analysis system consists of a stack of wafer scale components which individually provide the liquid flow channels, the capillary separation zones, the electrophoretic controls, the fluid logic and the detection system. This μCE system is more than an order of magnitude smaller in size than conventional laboratory bench top amino acid analytical instruments. Analysis times with μCE are on the order of a few minutes compared to almost an hour for HPLC-based analysis.

A critical aspect is that enantiomeric ratios can be rapidly and accurately determined using the microfabricated CE chip instrument. Using a sodium dodecyl sulfate/γ-cyclodextrin pH 10.0 carbonate electrophoresis buffer and a separation voltage of 550 V/cm at 10• C, baseline resolution is observed for the enantiomers of valine, alanine, glutamic acid, and aspartic acid in only 4 minutes (see **Figure 1**). Enantiomeric ratios of amino acids extracted from the Murchison meteorite using this μCE chip system closely matched values determined by HPLC (Hutt *et al.* 1999).

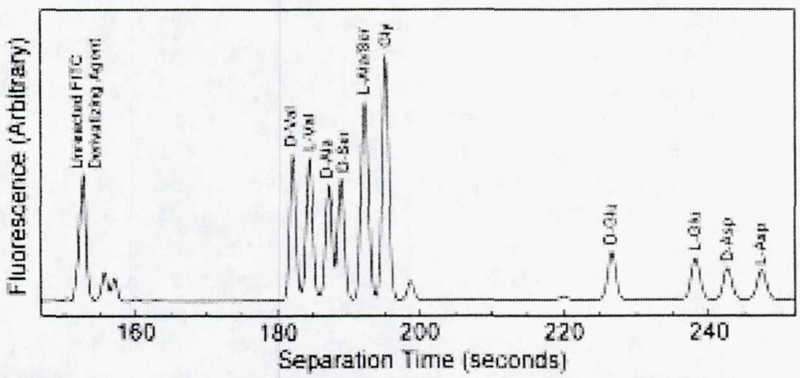

Figure 1: Baseline resolution of several amino acid enantiomers using the μCE chip system (taken from Hutt *et al.* 1999).

For spacecraft based analyses, a microfluidics-based sample processing system is required in order to delivery an amino acid extract suitable for analysis by a μCE system. In a design scheme presently being tested, amino acids are first extracted from a sample by a hot water/acid hydrolysis procedure. The aqueous extract obtained by this procedure is frozen and then sublimed at Mars ambient pressure onto a cold finger. The sublimed ice/amino acid mixture is thawed and collected into a reservoir interfaced with a μCE chip instrument. With this design, no desalting is required, thus eliminating a procedure which requires reagents and ion-exchange chromatography.

The reduced time, resources, and sample requirements for microfabricated CE chip instruments translate into a significant reduction in mass, power, and volume. With an estimated mass of ~1 kg, a volume of ~1000 cm^3 and a power requirement of ~2 W, the μCE chip system provides a compact, low-mass instrument suitable for a wide variety of *in situ* exobiology applications.

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5/14/91 2000110788 472667 pgs 2

SAMPLES FOR INVESTIGATIONS ON PAST AND/OR CURRENT BIOLOGICAL ACTIVITY ON MARS. M-C Maurel[1], [1]Institut Jacques Monod, Tour 43, 2 Place Jussieu 75251 Paris Cedex, France and the French C.S.E.E.M. e-mail : maurel@ijm.jussieu.fr

Introduction: Multi-disciplinary groups of biologists emerged in France as a result of two workshops (June1999 and January 2000) devoted to Mars sample return. The search based on the assumption that key engredients for life, liquid water and a source of energy are evidenced on ancient Mars, they are currently developing strategies to detect possible extinct and/or extant life on Mars. We can be sure that biosignatures of life, if there are, will be rare and to confirm this potentially controversial discovery the most sensible idea to address numerous questions is to bring safely to Earth laboratories selected samples from the surface and subsurface of Mars. It may be essential in order to claim extraordinary scientific conclusions to permit to do new and complete investigations. Most of them will be conducted under quarantine.

Objectives.
Mars exploration and samples analysis present a fundamental interest either for the scientists seeking for apparition of life on Earth and elsewhere, and for those interested by the definition of life, the understanding, the process and development of livings within ecosystems, and also those concerned by molecular mechanisms within the living cell, their adaptations and their evolution. Numerous fields are getting involved in these topics, for instance genomics, virology, microbiology, biochemistry, molecular biology, biophysics, studies of non-conventional organisms etc. This list is far from being exhaustive. Furthermore, combinatorial methods permit today the investigation of potential diversity of new macromolecules, and the emergence of a new molecular biology, perfecting new molecular tools etc [1, 2].
On the other hand, our capacity to detect life is an important issue. If there is no extant life, there is no biological risk.
Detection of life and biological tests for the risk will be done during a quarantine phase. Two main lines seem to have priority:
- Definition of a quarantine protocol including characterization analysis, detection and determination of hazards.
- Perfecting level 4 laboratories methods.
After quarantine, microbiologists, virologists and biologists experts in manipulation and detection of pathogen agents (including non-conventional ones) would be strongly involved in confinement and sample's conservation, in the short or long term.

In France, a level 4 laboratory (P4) [3] in Lyon, well-equipped with up-to-date facilities, and a confinement place to receive Mars samples are available.

The French biological community is strongly involved in the national activities in preparation of the Mars samples return mission. The demonstration was done with the large and expert participation to January 2000 workshop.
Some central themes were defined :
- definition of favorable conditions for life preservation:
The surface of Mars today is generally inhospitable to life. It is cold and dry and possibly there is a lot of salts. These conditions are favorable for the conservation of life and therefore for the preservation and identification of macromolecules or cellular structures, in particular in saline microenvironments. Many disciplines are involved in these topics, such as macromolecule's physico-chemistry, geochemistry, geomicrobiology etc..
- Interactions between micro-organisms and environments [4,5] could involded multidisplinaries teams of microbiologists, biochemists, geneticians and physicochemists to define metabolic and ecological limits in which life could have arose and evolved.
- definition of non-destructives manipulation techniques of Mars samples to detect life or bio-signatures and make a dynamical study of biological and bioorganic systems [6].

Perspectives:
Several teams of strongly complementary laboratories are working together in France for :
- The identification and reactivity of bio-organic molecules from the Martian samples. Reactivity means properties experimentally highlighted. This definition include biochemical functions and reactivities, for instance studies of non-genomic peptide synthesis
[7], weak chemical links which characterize biological molecules, identification of blocks of monomers (character-string like), tridimensional structure of polymers etc. In other words everything which make molecular activity.
This new structural biology tightly linked to reactivity requires methodologies combining physical and biochemical approaches. For instance studying decompo-

sition of peroxydes by biological complexes require a complementarity between Raman spectrometry and polarography [8]; SERS (surface enhanced Raman spectrometry) and infrared spectrometry shall allow us to understand polymerization, homologies and structural differences between informational precursors etc. On the other hand, we know today that DNA is robust and it is easy to extrapolate the same property for its precursors. Modeling studies will be performed in vitro using mineral/DNA (or analogs) assemblages to mimic the conditions prevailing on the Martian surface.

Also, the algorithmic theory of complexity and information theory will allow us to formally describe the finite and infinite complexity of sequences of characters. It is then possible to model certain syntactic structures of current genomes and of "non conventional" ones. These theoretical approaches will be experimentally validated using the systems optimized above.

The broad outline of this kind of programme is to optimizise the methodologies and to produce experiments under conditions mimicking those that are characteristic of the planet Mars (irradiation, temperature, pressure, hydrous potential, salts etc.)

- The study of micro-organisms adapted to extreme terrestrial environments in order to set up their biochemical machinery. The kind of adaptations (to energy sources, temperature, radiations etc.) will be useful to identify putative organisms adapted to the constraints of the present or past Martian environment [9].

The use of physical approaches for the study of the states of water and aqueous solutions under different conditions (with and without salts etc.) would be essential to the understanding of the development of living organisms. Furthermore, macromolecules which are the smallest scale of life appearance, are known to be well-conserved within salts [10]. To search for macromolecular signatures on Mars, it is of central interest to study the effects of environment and in particular of salts on the structure, stability, interactions and dynamics of molecules from these extremes.

This two examples are representative of richly multidisciplinary approach with expertise in biophysics, biochemistry, molecular biology and genetic, microbiology of halophile, thermophile and psychrophile organisms, physics of water etc...already working in France.

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MARTIAN NEUTRON ENERGY SPECTROMETER (MANES). R. H. Maurer[1], D. R. Roth[1], J. D. Kinnison[1], J. O. Goldsten[1], R. Fainchtein[1], and G. Badhwar[2], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, richard.maurer@jhuapl.edu, [2]Johnson Space Center, Houston, TX 77058.

Introduction: High energy charged particles of extra-galactic, galactic and solar origin collide with spacecraft structures and planetary atmospheres. These primaries create a number of secondary particles inside the structures or on the surfaces of planets to produce a significant radiation environment. This radiation is a threat to long term inhabitants and travelers for interplanetary missions and produces an increased risk of carcinogenesis, central nervous system (CNS) and DNA damage. Charged partcles are readily detected; but, neutrons, being electrically neutral, are much more difficult to monitor. These secondary neutrons are reported to contribute 30-60% of the dose equivalent in the Shuttle and MIR station (1).

The Martian atmosphere has an areal density of 37 g/cm^2 primarily of carbon dioxide molecules. This shallow atmosphere presents fewer mean free paths to the bombarding cosmic rays and solar particles. The secondary neutrons present at the surface of Mars will have undergone fewer generations of collisions and have higher energies than at sea level on Earth. Albedo neutrons produced by collsions with the Martian surface material will also contribute to the radiation environment.

The increased threat of radiation damage to humans on Mars occurs when neutrons of higher mean energy traverse the thin, dry Martian atmosphere and encounter water in the astronaut's body. Water, being hydrogeneous, efficiently moderates the high energy neutrons thereby slowing them as they penetrate deeply into the body. Consequently, greater radiation doses can be deposited in or near critical organs such as the liver or spleen than is the case on Earth. A second significant threat is the possibility of a high energy heavy ion or neutron causing a DNA double strand break in a single strike.

MANES Instrument Objectives: MANES was proposed in response to AO 99-HEDS-01for additional payloads to fly on the Mars 2003 Lander. The proposal was submitted in August 1999 and was selected for the definition phase in November 1999.

The MANES instrument is partitioned into two channels—the Low Energy Spectrometer (LES) and the High Energy Spectrometer (HES)—which are mounted to a central housing containing the electronics to operate the instrument and provide the spacecraft interface. It will have a mass of 5 kg and measure the Martian neutron spectrum over a large energy range. Specific objectives for MANES are

1) measure the neutron fluence energy spectrum on the surface of Mars over an energy range from 100 keV to 50 MeV with a goal of 20 keV to 100 MeV;
2) monitor both the diurnal and solar cycle time variations in the neutron environment;
3) compare the measured neutron spectra to models that propagate the incident cosmic ray spectrum through the Martian atmosphere and calculate the reflected albedo from the Martian surface;
4) determine the neutron directionality ratio;
5) measure the fluence ratios of protons to alphas to heavy ion groups in the HES anti-coincidence shield for the incident charged particles;
6) from the results, calculate the dose, dose rate, dose equivalent and dose equivalent rate to be expected by astronauts on Mars.

MANES Instrument Design: The LES uses a helium 3 gas tube to measure neutrons in the energy range from 100 keV or less to about 5 MeV. Two of these tubes will be flown with some polyethylene absorber to help determine differences between the propagated and reflected neutron spectra (directionality). The tubes will operate in both the common ^{3}He(n,p)^{3}H neutron absorption reaction mode and in the elastic neutron scattering mode that monitors the ^{3}He recoil. The absorption reaction has an energy release of Q=0.764 MeV which is added to the incident neutron energy. The spectrum has peaks corresponding to the most prominent neutron energies plus the Q of the reaction. If a thermal neutron peak is present as at sea level on Earth, it will provide a continuous energy calibration. Modeling and beam facility testing will provide necessary corrections for tube efficiency and the elastic scattering transfer function.

The HES will consist of a pair of 5-7 mm thick, 3 cm^2 lithium drifted silicon detectors ganged together to maximize the number of targets or fractions of a mean free path presented to the natural neutron beam. Charged silicon recoil nuclei, nuclear fragments, protons and alphas are progeny of the neutron-silicon collisions in the detector and their ionization depositions are collected and measured by standard pulse height techniques. Both elastic and inelastic reactions contribute to the total solid state detector efficiency. A thick detector offers increased efficiency which is important as the neutron energy increases to tens of MeV.

The silicon detectors will be surrounded by a CsI cup and plug scintillators that will serve to veto charged particle depositions in the silicon. In addition to using the CsI as an anti-coincidence shield, we will record the light in the CsI with PIN photodiodes to yield information on charged particle ion groups. The plug or puck will face the Martian surface and also be able to record information on the most prominent gamma rays emitted from the soil. Rise time

discrimination methodology will be used to distinguish the different types of radiation.

Results: Engineering prototype gas tube and silicon solid state detectors have been tested and evaluated since 1998 under funding from the National Space Biomedical Research Institute (NSBRI) through NASA Cooperative Agreement NCC 9-58. Testing of detectors has been carried out with Cf, PuBe and AmBe radioactive neutron decay/spallation sources and with mono-energetic neutron beams. The Columbia University Radiological Research Accelerator Facility (RARAF) supplied mono-energetic neutrons between the energies of 0.5 and 20 MeV by the use of p-t, d-d and d-t reactions. RARAF is an NIH supported resource center through grants RR-11623 (NCRR) and CA-37967 (NCI).

The ^{3}He gas tube detector has consistently shown the classic responses to both radioactive and beam neutrons. Wall effect, epithermal, recoil and absorption count peaks are readily resolved in the pulse height spectra. For example, for 2.46 MeV neutrons the ^{3}He(n,n)^{3}He elastic recoil reaction produces short rise time pulses while the ^{3}He(n,p)^{3}H absorption/capture reaction produces long rise time pulses. Pulse rise time is used to discriminate between the two effects. The full width at half maximum of the epithermal peak is about 25 KeV and indicative of the LES detector energy resolution. The greater width of the neutron absorption peak is due mainly to the energy spread of the incident neutron beam. Data plots will be presented on these results.

The 5mm thick lithium drifted silicon solid state detector has been evaluated using mono-energetic neutron beams at RARAF. Since the cross section for the neutron capture rection in the gas tube falls precipitously above 1-2 MeV, a more dense detector medium must be used for the higher neutron energies. Neutron energies of 5.9, 14, 16.25 and 18.5 MeV were used to determine the overall efficiency and deposited enrgy spectra. The spectra observed over this energy range show considerable structure since we are in a region where nuclear resonances are prominent. The lowest energy deposition events give a smooth response and are due to the elastic scatter of the incident neutrons from the silicon detector nuclei and extend from our low energy detector cutoff (250 KeV as determined by noise) to 0.133 times the incident neutron energy as determined by the kinematics of the silicon recoil nucleus in the elastic reaction. An intermediate energy deposition region with minor structure is due to the moderately sized recoil fragments in the inelastic collisions including resonance excitation and decay. An example of such a fragment is a magnesium nucleus produced in a neutron-silicon collision that also creates an alpha particle. The high energy end of the deposition spectrum contains significant structure in the form of peaks which have energies up to the incident neutron energy and are due to a superposition of various proton and alpha particle states. The different energies of these peaks are determined by the kinetic energy given the proton or alpha particle in the different inelastic collision excitation and decay states. Again data plots will be presented.

The efficiency of the silicon detector is governed by the total cross section for neutron-silicon reaction as a function of energy. The experimental efficiency for the 5mm thick detector in the neutron energy range of 5.9 to 18.5 MeV was determined to be 4-5%. We compared our experimental results with both NASA deterministic (2) and Dept. of Energy Monte Carlo (3) models and found very good agreement for efficiency. This agreement indicates that MANES can efficiently measure neutrons in the 5-20 MeV range. Since the models predict the efficiency to be greater than 3% out to neutron energies of 100-150 MeV, we expect our bulk silicon detector to be useful at these higher energies as well.

Modeling: We are using the CERN GEANT4 software suite (4) to model our experimental results and run virtual experiments on our detector configuration. The GEANT4 code uses the Evaluated Nuclear Data Files (ENDF) as input for all particle reactions. It tracks all products of reactions and conserves energy at each reaction point. We have reproduced both the experimental detector efficiency and high energy deposition events for our 18.5 MeV runs at RARAF and are in the process of completely simulating all our RARAF experiments. Our ultimate objective is to develop a complete transfer function for MANES to deduce the most probable incident neutron spectrum.

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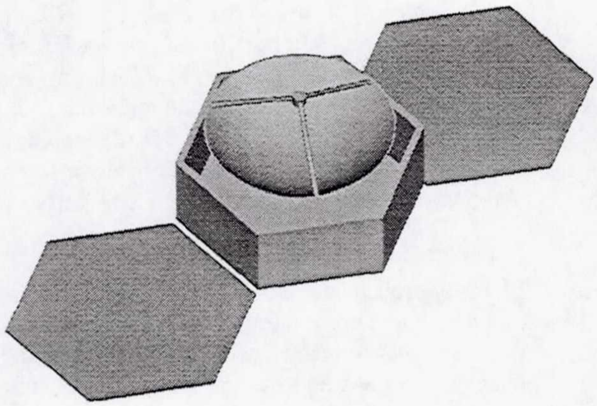
2000110790

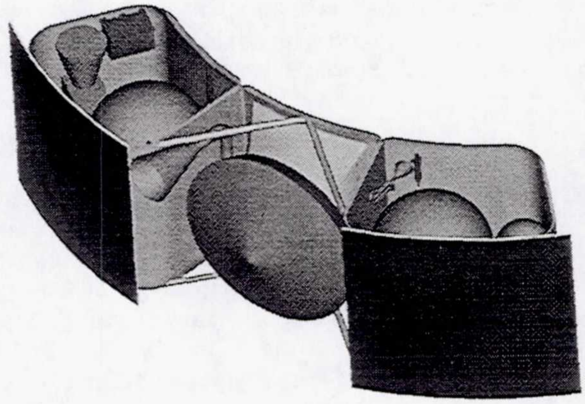
Science-Enabling MicroSpacecraft Constellations for Mars. A. Mauritz[1] and B. Patel[2], [1]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, mauritz.ann@orbital.com, [2]Orbital Sciences Corporation, 21700 Atlantic Boulevard, Dulles, VA 20166, patel.bhavesh@orbital.com

By leveraging commercially-developed spacecraft constellation technology, a wide variety of Mars missions can be accomplished ranging from single microspacecraft missions costing less than $50 million to constellations of microspacecraft that provide distributed remote sensing capabilities. Remote sensing missions that require global coverage of Mars can be conducted by constellations of microspacecraft. These microspacecraft provide focused science at low risk. As an additional benefit, these microspacecraft could easily be modified to provide the communication and navigation infrastructure necessary for other complimentary surface science missions.

Orbital Sciences Corporation has extensive experience developing and operating microspacecraft constellations. The figures below illustrate microspacecraft designs applicable to a wide variety of Mars missions. Based on the highly proven Microstar bus, this spacecraft is capable of dedicated or shared launches on a number of launch vehicles including Pegasus, Taurus, Delta II, Delta III, and Ariane 5. Missions enabled by these microspacecraft include constellation-based scientific remote sensing, communications relay, navigation, and distributed aperture sensing. Additionally, this bus can support singular missions focused on probe delivery, remote sensing, or remote monitoring of, and data collection from land-based elements conducting Mars insitu science.

The spacecraft bus utilizes a common set of low mass, low power avionics successfully demonstrated on 38 MicroStar spacecraft currently in operation. By optimizing mechanical designs around specific launch vehicles and payloads, this bus offers a robust means by which to realize many missions. Depending on launch vehicle capability, this bus can support payloads weighing up 70 kg with average payload power requirements in excess of 50W. These proven spacecraft platforms provide an affordable means by which to execute exciting science missions at low risk.





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P3 l

Autonomous Behavior via Multi Parallax Biomimetic Vision Systems. E. D. McCullough

Autonomous behavior based on the simultaneous correlation of multiple visual perspectives with stored data can be used to improve rover performance in difficult terrain on mars, control terminal phases behavior of a planetary descent vehicle and enable autonomous proximity operations near satellites and the Space Station. The stored data is obtained via a training process conducted in rugged and hazardous terrain on earth to establish a baseline of geometric situations and imperatives / constraints which bound the vehicles behavioral options on Mars. This approach would also provide the geometric situational awareness required for a biomimetic vehicle for scaling Martian cliffs. This technology updates Scene Mapping Area Correlator (SMAC) and Digital Scene Mapping Area Correlator (Digi-SMAC) technologies with current terabyte memory, photonics, fast processor technology and the vision system of an arachnid. The autonomous behavior is an emergent property of rapid correlation of geometric constraints.

In this approach, multiple images from different viewpoints are tiled into a composite image (for example a 2x4 array) and correlated with a set of stored tiled images in order to find the closest match. All the input images are correlated simultaneously and a match means that the current geometry around the viewpoints matches the geometry of the selected stored image to a greater degree than any of the others. The use of multiple images increases the number of parallaxes from 1 (humans) to 28 (arachnids) etc. Simultaneous correlation makes the information contained in the additional parallaxes available for guiding vehicle behavior. The correlation is simplified as much as possible to reduce processing loads and is biased to account for time of day, azimuth orientation and sun angle. Additional biases take into account vehicle velocity.

Tiled images along with motion control instructions are placed in the memory by the operator during training activities on Earth. The usage of these stored images and associated data will allow the issuance of motion commands to known points and orientations without path definitions. The vehicle moves from one location to another minding the geometry/velocity (situation) constraints contained in memory. The terabyte memory is necessary to store the required images and data for all the situations in the training program. This training program will also include high speed operation.

Many approaches to terabyte memories are being developed. One of them, the bacteriorhodopsin cube developed by Dr. Robert Birge, can access 200 million memory pages per second. The low access times of these devices combined with the speed of current processors allows the system to go through a full range of constraints to identify hazardous or unsafe geometric/dynamic situations and to modify vehicle velocity and goals accordingly.

As an example, consider a rover with an arachnid vision system.

The rover has 2 eyes mounted on the upper rear corners of the vehicle, 2 mounted high on the front facing forward, 2 mounted on the front of the vehicle facing forward upwards and 2 mounted on the upper front corners of the vehicle facing forward and sideways. All of the eyes view > 2 Pi steradians except for the 2 mounted high and forward which are telescopic and view much less than 1 steradian. The images are detected at each viewpoint with separate CCDs or passively spectrally encoded and sent through fibers to a passive decoder and detected with a single CCD. The acquired images are combined into one tilled image which is compared with similarly tiled images in the terabyte memory data base until the closest match is found. Additional data stored in association with the retrieved image is used to define what the vehicle's behavioral options.

The techniques used in this example could enable many autonomous tasks such as autolanding of Mars descent vehicles, autolanding of helicopters, controlling a set of autonomous vehicles flying in formation with a human piloted aircraft. The technique can be modified to accomplish auto surgery (for example auto removal of thyroid glands in animal carcasses,) auto assembly, auto recognition of fossils, expert control of vehicle subsystems (IVHM,) and interpretation of histograms and spectral data.

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MARS METEOR SURVEY. R. D. McGown, B. E. Walden, T. L. Billings, C. L. York, A. G. Taylor, and R. D. Frederick[1], [1]Mars Instrument and Science Team (MIST), Oregon L5 Society, Inc., P.O. Box 86, Oregon City, OR 97045, email moonbase@home.com.

Proposal: We propose instruments be included on one or more Mars landers to identify and characterize the meteoroid flux at Mars.

Rationale: Mars orbiting spacecraft and ground operations, both manned and unmanned, are vulner-able to meteoroids. There is pure scientific interest in knowing the frequency, intensity, and radiants of mar-tian meteor showers. Being in a different orbit than Earth and closer to the asteroid belt, Mars has un-known cycles and intensities of meteoroid hazards. Knowledge of these hazards can help us manage risk in future missions, particularly extended and crewed missions.

Instruments: To be most effective the detectors should be continuously active, day and night, for as long a period as possible. Detectors that rely on en-ergy-intensive transmitters, such as lasers, radio bounce or radar [1], are therefore less desirable. A staring instrument is preferable to one which must rapidly skew to track a meteor (requiring extra me-chanical parts and susceptible to failure), and should be able to detect multiple meteors simultaneously.

Power Supply In order to obtain representative samples and reliable long-term statistics, a power sup-ply that can maintain function during the martian night and over the martian winter is highly desirable. Ideally the power supply should provide several years of service.

Camera A staring full-sky camera can detect me-teors directly, at least at night (meteor being the flash of light in the atmosphere caused by an infalling mete-oroid). It may be possible to detect them in daylight as well, perhaps using an infrared (IR) camera. Ultra-wide angle 180° lenses are expensive and bulky. A small camera staring down at a lightweight spherical mirror can cover the sky just as well and may be better for dust management. The optics need not be of astro-nomical quality to gather this statistical data, and the small portions of the sky obscured by the camera and its support are relatively insignificant.

Spectrograph Spectrographic capability would give us information about the elemental compositions of Mars' upper atmosphere and the vaporizing meteor-oids. Radial velocity can be determined by doppler shift and combined with transverse velocity to yield a true vector solution for the meteor.

Radio The ionization created by meteoroid entry generates a radio-frequency (RF) signal. It may be possible to detect this emission and derive certain in-formation from it. A radio (or microwave) detector can work day or night. It may also be able to detect smaller magnitude events than an optical/IR detector. In order to localize the signal, at least three receivers and an-tennas are required. It may be possible to integrate the antennas as part of a splayed landing gear array. An-other possibility is to make the optical camera support legs into antennas.

Microphone If a microphone is included as part of another package, some larger, closer meteoroids could produce a sonic boom or other detectable sound. Being able to associate the sound with a detected meteor would help us characterize the nature of sound trans-mission and attenuation through the martian atmos-phere.

Barometer If a barometer is included as part of a martian weather package, it might also record the sonic boom sometimes associated with meteors.

Seismometer If a seismometer is included in a geology package, on this or other landers, coincidence of a seismic signal with a meteor detection could be a confirmation of impact. Further analysis of the seismic signal could help calibrate the meteor detector.

Computer An onboard computer can process the raw data so only a small set of data, consisting of basic meteor identifying parameters, need be included in periodic uploads to Earth. For diagnostic and other scientific purposes, it should be possible to bypass the computer and send broadband raw data to Earth.

Questions: Here are some questions the Mars Meteor Survey might address:

When are martian meteor showers, how big are they, and where do they come from?

Which meteors come from the asteroid belt and which from comets?

Will Mars surface operations be exposed to periodic "rains of rock"? (Fig. 1)

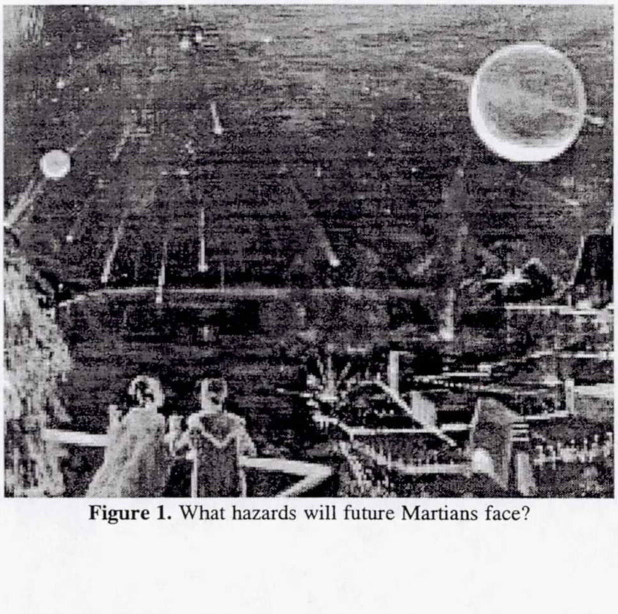

Figure 1. What hazards will future Martians face?

Can we predict meteor showers and storms on Mars?

What is the cumulative risk to surface and orbital operations at Mars due to meteoroids?

How small can a meteoroid be and still reach the surface of Mars?

Are meteorite falls on Mars different in characteristics or time frames from those on Earth?

Would radio or microwave receivers on Mars be sufficient to detect meteors without a reference trans-mitter?

What will meteors look like on Mars? Will they have statistically different characteristics than those seen on Earth?

Are there dust zones or gradients in Mars' atmosphere?

Can wind-shear zones or jet streams in Mars' atmosphere effect meteor signals? [2]

How much of atmospheric dust on Mars is endo-genic (kicked up from the surface) and how much exo-genic (meteoroid)?

Is there a synergy between radio and visible/IR or spectrographic sensors to characterize mass, composition, or other factors of meteoroids or of the martian atmosphere?

Are there statistical differences in composition of Mars meteoroids vs. Earth meteoroids?

Can the Mars Meteor Survey instruments be used in other studies, such as dust storm analysis, imaging during the landing sequence, etc.?

Does Mars have additional small moons?

Further Work: Research existing knowledge from Pathfinder and other missions to better under-stand the martian atmosphere. Find examples of re-corded martian meteors, in order to establish parame-ters for Mars Meteor Survey instruments. Research Earth-based "staring" experiments to identify detection techniques, analysis algorithms, and possible problem areas. Predict possible times for Mars meteor showers based on known Mars-crossing comets, and compare these predictions to actual results. Cooperate with other researchers and planners to create a specific pro-posal for flight. Identify sources and acquire funding to build and fly the Mars Meteor Survey instruments and analyze their data. Publish and disseminate results of the experiment.

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Assistance Sought: The Oregon L5 Mars Instru-ment and Science Team would like to work with other professionals in the field to produce the Mars Meteor Survey. Please contact chairman Gus Frederick, gus@norwebster.com, (503) 873-6216 or write to the address above.

5,9/35 2000116793 472681 pgs 2

Mars Immunoassay Life Detection Instrument (MILDI)

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The direct detection of organic biomarkers for living or fossil microbes on Mars by an insitu instrument is a worthy goal for future lander missions. We have proposed an instrument based on immunological reactions to specific antibodies to cause activation of fluorescent stains. Antibodies are raised or acquired to a variety of general and specific substances that might be in Mars soil. These antibodies are then combined with various fluorescent stains and applied to small numbered spots on a small (2-3cm) test plate where they become firmly attached after drying. On Mars, a sample of soil from a trench or drill core is extracted with water and/or an organic solvent that is then applied to the test plate. Any substance, which has an antibody on the test plate, will react with its antibody and activate its fluorescent stain. A small UV light source will illuminate the test plate, which is observed with a small CCD camera. The numbered spots that fluoresce indicate the presence of the tested-for substance, and the intensity indicates relative amounts. The entire instrument can be quite small and light, on the order of 10 cm in each dimension. A possible choice for light source may be small UV lasers at several wavelengths. Up to 1000 different sample spots can be placed on a plate 3 cm on a side, but a more practical number might be 100. Each antibody can have a redundant position for independent verification of reaction. Some of the wells or spots can contain simply standard fluorescent stains used to detect live cells, dead cells, DNA, etc. These the stains in these spots may be directly activated; no antibodies are necessary.

The system can look for three classes of biomarkers: those from extant life such as DNA, those from extinct life such as hopanes, and those from organic compounds not necessarily associated with life such as PAHs. Both monoclonal and polyclonal antibodies can used. Monoclonal antibodies react with a very specific compound, but polyclonal antibodies may react to any of a whole family of compounds. Consequently, we do not have to guess which specific compounds may be present on Mars, only which broad families of compounds. Using both kinds increases the chances for hits.

Examples of potential biomarkers for which antibodies may be produced:

1. DNA, RNA and individual bases nucleotides including novel nucleotides used by the archaebacteria.
2. ATP and ATP reductase.
3. Cyclic adenosine monophospate.
4. Hopanes and other steroid-based membrane components which are known to survive for up to 2.5 billion years on Earth as specific biomarkers.
5. Lipopolysaccharides, probably of a cross section of species.
6. General Exopolymeric substances.
7. Porphyrins, including cytochromes, chlorophyll a, bacteriochlorophyll and the Ni and VO replaced porphyrin biomarkers found in oils.
8. 8.Teichoic acids.
9. Specific amino acid or peptide sequences.
10. Flavin adenine dinucleotide (FAD) and nicotinamide adenine dinucleotide (NAD).
11. Antarctic cryptoendolithic biomarkers, specifically the specialized cryoprotectants and UV protectants such as Scytanemin
12. RUBISCO
13. Hydrogenase.
14. Nitrate reductase.
15. Specific PAHs

This list is not exhaustive but serves to illustrate the possibilities. Not only would such a test be able to indicate if traces of viable or non-viable life are present, if that life were viable, this list would enable biologists to determine what its composition was and even something about the metabolism of the organisms.

One aspect of this proposed experiment is that it must be extensively tested on a variety of terrestrial materials including soils to determine its detection limits, its propensity for false positives, and its ability to discriminate among related compounds. Work is currently underway to choose and evaluate a set of reasonable antibodies. Extensive laboratory testing of the antibodies must be done. The mechanical design of the instrument is also beginning. A major objective is to keep the instrument small and simple.

An important feature of the instrument is its potential for multiple missions. Based on the results of the first mission, the mix of antibodies can be modified, and the instrument can be flown again tailored to zero in some additional likely compounds.

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PLANETARY MICROBIAL ECOLOGY ON MARS: ENVIRONMENTAL BIOPHYSICS OF MARTIAN MICROENVIRONMENTS. A. Méndez, Department of Physics and Chemistry, University of Puerto Rico at Arecibo (a_mendez@cuta.upr.clu.edu)

Introduction: Earth's planetary habitable zone, the biosphere, includes parts of the atmosphere, hydrosphere and lithosphere (see figure) [1]. Microbial life thrives within this region due to the availability of liquid water, an energy source, nutrients and the right environment. The field of microbial ecology studies the interactions of microbial life with the environment. There are many models and techniques within this field that can be extrapolated to understand the possibilities and limitations of microbial life on Mars past or present environments. The objective of this work is to demonstrate the importance of microbial ecology research on future Mars exploration. The biological relevance of the physical microenvironment characterization of Mars is presented.

Physical Requirements of Life: The environment temperature, pressure, heat transfer (i.e. convection due to wind) and water content are some of the basic physical quantities that affects the microbial physiology. In particular, temperature and pressure are very important as they control the reaction and diffusion rates of the cell's biochemicals. Although much has been studied about the effects of temperature on microorganisms, little is known about the combined effects of pressures and temperatures on microbial growth. Most known microorganisms require an environment temperature for optimum growth of 310 K at standard atmospheric pressure (1.013 bars), but microbial growth is possible between 253 K and 386 K [2,3]. About 85% of the cultured prokaryotes have optimum growth temperatures between 295 and 315 K [4]. This range is outside Earth's average surface temperature (288 K) but it is consistent with the average surface and subsurface temperatures of the equatorial regions on Earth [5].

Steady hydrostatic pressure changes have little or no effect on the growth and metabolism of most microorganisms. Growth of most terrestrial microorganisms is retarded between 300 and 400 bars at 303 K. At 600 bars most terrestrial microorganisms are sterilized, only a few species of marine bacteria grow at such pressure or higher at temperatures between 303 and 313 K [6]. In general, lower temperatures accentuated the growth retarding and sterilizing effects of pressure. Some deep-sea obligately barophilic bacteria are not able to grow at pressures of less than 500 bars, but are able to grow well at higher pressures, even at 1000 bars [7].

There has been little interest about microbial growth at temperatures and pressures similar to the Mars environment. This may be due to the remote or lack of natural Earth's environments with similar conditions (i.e. high altitude mountains). For example, it will be very interesting to determinate if the current martian near-surface environment, protected from UV radiation, provides the necessary physical environment for microbial growth, assuming the other requirements for life are present (i.e. temporal availability of water).

Mars Microenvironment: A microenvironment usually is extremely variable over short space and time scales, but its characterization is necessary when considering organisms mass and energy exchanges. Traditionally, the field of environmental biophysics studies the energy and mass exchanges between living organisms and their environment. In general, it deals with the basic environmental variables: temperature, humidity, wind and radiation. An energy budget equation is used to describe the fitness of the physical environment for life (i.e. microbial growth) given these variables [8].

Characterization of the Mars near-surface microenvironment for biophysical applications will require at least three vertical measurements of temperature, wind velocity, and water content in the atmosphere, and temperature and water content in the soil. Measurements at one location of atmospheric pressure and irradiance will be necessary. This measurements are required as function of time for various sols or seasons to quantify biophysical relevant parameters such as the thermal diffusivity, heat capacity and thermal conductivity of the martian soil. This data can be used to estimate, from the energy budget equation, the minimum energy requirements for microbial growth in the martian surface layer protected from UV radiation and other hazards (i.e. oxidants). This has implications in planetary protection issues about forward and backward contamination risks between Earth and Mars.

Discussion: The characterization of some of Mars' near-surface microenvironments will have more applications besides surface layer physics. They will provide the tools to understand possible biological processes in the Mars' environment. In general, research in this field will:

1. Provide biophysical relevant data to calculate mass and energy transfers between the Mars' environment and microbial life. This will be useful to esti-

mate the potential habitability of Mars by exogenous or indigenous microorganisms.

2. Stimulate and improve theoretical and laboratory simulations about microbial life and possible ecological interactions on the Mars environment.
3. Expand the traditional microbial ecology field, here named "planetary microbial ecology." This field will study the interactions of life with planetary environments including Earth. It is an invitation to microbial ecology scientists to extrapolate their models and techniques to planetary environments such as Mars.

This work only discussed those environmental biophysics relevant considerations for future Mars exploration. They represent the basic physical understanding necessary for geochemical and biochemical studies about planetary microbial ecology on Mars.

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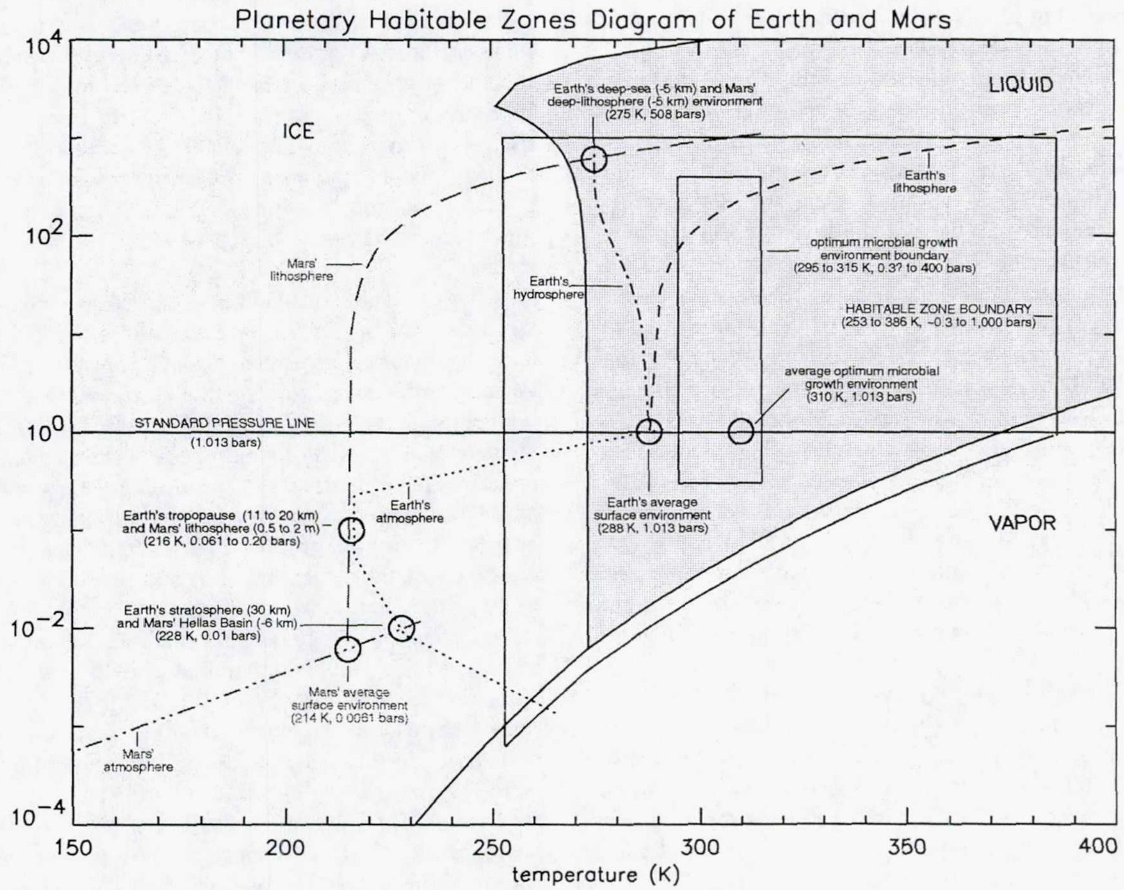

Figure: The Planetary Habitable Zones (PHZ) diagram shows the global-mean steady-state vertical environment physical state of Earth and Mars. In general, the habitable zone boundary delimitates the environment physical state where microbial growth is possible. Outside of this boundary microorganisms are either sterilized or preserved in a dormant state. Growth is also restricted within this boundary due to other factors like the availability of water, an energy source, nutrients, and the particular microbial physiology [1, 5].

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P5 2

Robotic Arms: A Critical Element of any Mars Landed Mission. J. A. Middleton[1], C. S. Sallaberger[2] and T. J. Reedman[3], [1]Vice-President, Strategic Development, MD Space and Advanced Robotics, 9445 Airport Road, Brampton, Ontario, Canada L6S 4J3, jmiddlet@mdrobotics.ca, [2],Director, Space Exploration, MD Space and Advanced Robotics, 9445 Airport Road, Brampton, Ontario, Canada L6S 4J3, csallabe@mdrobotics.ca, [3]Chief Engineer, Advanced Systems Group, MD Space and Advanced Robotics, 9445 Airport Road, Brampton, Ontario, Canada L6S 4J3, treedman@mdrobotics.ca.

Introduction: Landed exploration of Mars requires robust robotic systems capable of satisfying the demands of multiple scientific users. Whether the landed system is a stationary lander or a mobile rover, a robotic arm is an essential element of an exploration system that satisfies scientific needs while providing a method of dealing with unexpected contingencies.

The basic purpose of any landed system is to explore and examine the surface and sub-surface of the planet in question, perhaps in conjunction with technology demonstration elements. To this end the basic needs for exploration are the deployment and retrieval of experiments to and from the surface, the acquisition of surface and sub-surface samples for analysis, and the imaging of the local environment.

A robotic arm satisfies these requirements in a resource efficient manner and also adds an element of robustness to the system.

Mission Architecture: A typical landed exploration system has as its central element a science platform (either static or mobile) capable of supporting a wide range of scientific payloads to examine and determine the state of the planet's surface. The highest level needs for such a system are to:

1. Deploy experiments and instruments of varying sizes to the planet's surface
2. Acquire surface and sub-surface samples and provide them to science instruments for local analysis.
3. Acquire surface and sub-surface samples and transfer to the sample return vehicle (for sample return missions)
4. Provide imagery of the local terrain

An overarching requirement not listed above is the need for a robust system that minimizes the risk of mission failure.

Capabilities. These system needs can be synthesized into the following necessary system capabilities:

1. Handling of multiple payloads varying in size from soil samples on the order of many grams to a rover on the order of many kilograms.
2. Provision of power and data connections to payloads.
3. Dexterity in payload handling to ensure accurate placement and orientation of payloads on either the science deck or the planet surface.
4. Force application sufficient to react both digging and drilling loads
5. Camera support to allow varied imaging of the local workspace.

Generic System Architecture: A robotic arm can used as the basis for a generic system architecture that effectively provides these capabilities, for missions ranging in size from the Mars Surveyor class landed systems to small Beagle II type landers.

Such a robotic arm would require between 4 and 6 degrees of freedom depending on the specific mission needs. Mass, power and load capacity would be commensurate with the landed system size. The end effector would be capable of handling and servicing many different payloads, varying from digging tools to science instruments. To deal with the limited communications available, the system would be semi-autonomous and capable of some self-diagnosis.

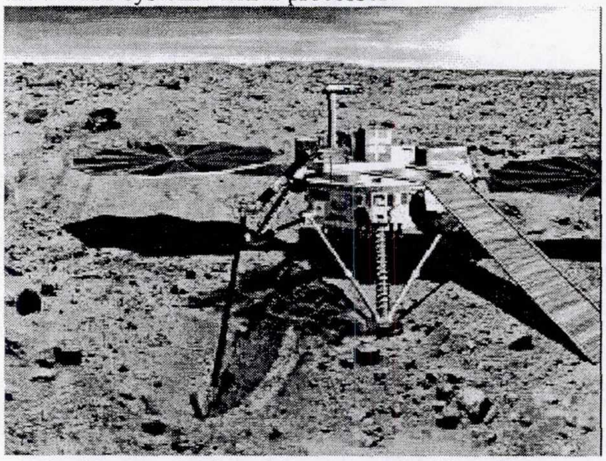
An Illustrative Application: This approach was recently the subject of a feasibility study conducted by MD Robotics, where a systems engineering approach to the mission architecture derived a robotic arm as a solution to the needs of the Mars Sample Return Missions.

System Description. The robotic arm was a 4 degree of freedom pitch plane manipulator with a mass of 7 kg including processing electronics. Power consumed varied between 10 and 20 watts depending on the operating mode and the task being performed. The manipulator had a maximum reach of 2.8m allowing a 2.2m radius surface work area. The manipulator tip was equipped with a multi-purpose end effector capable of handling payloads ranging from an 8 kg sampling drill to rover samples. In order to avoid duplication of existing lander functionality, for the Mars 2003 mission a camera was not included in the arm manifest; however, structural and electrical scarring for a camera was provided.

The tasks envisioned for the arm included experiment deployment and sample acquisition and transfer.

The needs of the scientific community were met through the use of a multi-purpose end effector that

allowed the handling of diverse payloads. Power and data lines routed along the arm were connected to the current payload via an umbilical mechanism to allow experiment operation, control and data acquisition by the landed system central processor.



In this proposed architecture, valuable mission robustness was achieved simply by having a flexible, reconfigurable robot in-situ. Should a problem have arisen in the deployment of another lander system the robot arm could be used to investigate the anomaly, providing the earthbound system operators with insight into the situation. If force were required to assist in deployment of a stuck system such as an antenna, the arm could have provided the required impetus.

Risk Management: The utility of a robotic arm in managing mission risk is perhaps best illustrated by considering its potential application in the original Mars sample return missions. The Athena rover was seen as the primary sample retrieval chain. It was deployed by driving down ramps extended from the Lander deck and had to re-ascend the ramps to transfer its samples to the ascent vehicle. The secondary sample retrieval chain was a coring drill, deployed using a simple positioning mechanism.

Using a robotic arm on this mission to deploy the coring drill for its sample acquisition activities created some useful risk management possibilities. For instance, while the arm's primary task was to support the secondary sample retrieval by deploying the coring drill, it could also be used to backstop the primary sample retrieval chain. If the rover ramps became stuck during deployment, the arm could be used to apply assistive force. If the rover required assistance during deployment, the arm could once again apply assistive force. If the rover had difficulty ascending the ramps to transfer its sample to the ascent vehicle, the arm could be used to acquire the samples from the rover on the planet's surface and then deposit them in the ascent vehicle.

In this example application, the robotic arm effectively mitigates mission risk while providing basic functionality for the core mission objective, namely sample retrieval. Other possible contingency activities include assisting in antenna deployment and the cleaning of dust covered optical surfaces such as solar arrays.

Conclusions: A robotic arm should be part of the infrastructure of any multi-purpose landed Mars mission as a method of efficiently deploying and supporting instruments, performing sample collection and sample distribution, while also significantly enhancing mission robustness through its capabilities for contingency operations.

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THE SEARCH FOR WATER AND OTHER VOLATILES IN MARTIAN SURFACE MATERIALS: THE THERMAL EVOLVED GAS ANALYZER (TEGA). D. W. Ming[1], W. V. Boynton[2], D. S. Musselwhite[2], S. H. Bailey[2], R. C. Bode[2], G. Quadlander[2], K. E. Kerry[2], M. G. Ward[2], R. D. Lorenz[2], A. V. Pathare[3], D. A. Kring[2], H. V. Lauer, Jr.[1], D. C. Golden[1], I-C. Lin[1], and R. V. Morris[1]; [1]NASA Johnson Space Center, Houston, Texas 77058 (douglas.w.ming1@jsc.nasa.gov), [2]University of Arizona, Tucson, Arizona 85721, and [3]University of California, Los Angeles, California 90024.

Introduction: Volatile-bearing minerals and phases (e.g., Fe-oxyhydroxides, phyllosilicates, carbonates, sulfates, palagonites, glasses) may be important components of the Martian regolith. However, essentially no information exists on the mineralogical composition of volatile-bearing phases in the regolith. The Thermal Evolved Gas Analyzer (TEGA), which was part of the Mars Polar Lander payload, was to determine the abundances of two of the most important volatile compounds (i.e., water and carbon dioxide) in the martian soil and to identify the minerals or phases that harbor these volatiles. The TEGA instrument was composed of a differential scanning calorimeter (DSC) interfaced with evolved gas analysis (EGA) [1,2]. The EGA consisted of a Herriott cell of a tunable-diode laser (TDL) spectrometer that determines CO_2 and H_2O abundances. The sample chamber was to operate at about 100 mbar (~76 torr) with a N_2 carrier gas flow of 0.4 sccm. Specifications of TEGA are described in detail elsewhere in this volume [2].

TEGA Calibrations: Prior to landing on Mars, the TEGA science and engineering team performed numerous calibrations using a TEGA Engineering Qualification Model (TEGA-EQM) located on the University of Arizona's campus. A TEGA laboratory test bed was also developed at NASA Johnson Space Center (JSC) in order to compile a mineral database for the thermal behavior of volatile-bearing phases under reduced pressures appropriate for the flight TEGA. The JSC test bed consisted of a laboratory DSC integrated with a quadrupole mass spectrometer (QMS).

A wide variety of volatile-bearing phases were analyzed by the JSC laboratory test bed, including Fe-oxides/oxyhydroxides/sulfides, phyllosilicates, sulfates, carbonates, palagonites, oxides/peroxides, and zeolites [2]. Reduced pressure operating conditions in the DSC significantly changed the thermal behavior of most volatile-bearing phases as compared to ambient pressure (1000 mbar N_2) operating conditions. In most cases, the onset temperatures for a volatile-release event decreased under reduced pressure operating conditions (e.g., [3,4,5,6]).

The mineral database for thermal responses under reduced pressure operating conditions was used to characterize geological unknown samples that were run on the TEGA-EQM. Here we briefly describe one of those unknown runs that was used for the TEGA Mission Operation Readiness Test (MORT) [7]. R. V. Morris provided the unknown geologic sample to the TEGA team.

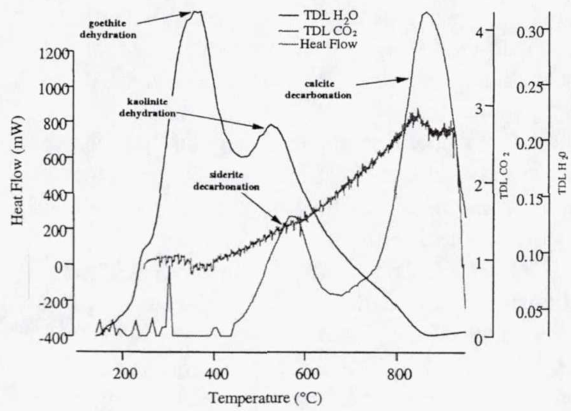

Figure 1. *DSC and evolved CO_2 and H_2O from geologic unknown as determined by TEGA-EQM.*

The unknown geologic sample was first run on the TEGA-EQM. Operating procedures for the run were analogous to the operating procedures planned for the first experiment on Mars. The TEGA-EQM run is shown in Figure 1. From the EGA data, it is clear that there were two major water releases and two decarbonation events. The second decarbonation peak with an onset temperature around 780°C was also clearly evident in DSC as an endothermic response. Based upon the DSC and EGA signatures obtained during the TEGA-EQM run, we used our mineral database to derive a "first guess" sample. The "first guess" sample was composed of siderite, calcite, poorly-crystalline kaolinite, and goethite (Table 1). We ran the "first guess" sample on the JSC laboratory test bed. Although the DSC and EGA signatures were similar to those of the geologic unknown sample, the low-temperature water release for the "first guess" sample did not fit the water release in the unknown run. We added an unaltered tephra from the Puu Huluhulu cinder cone in Hawaii and slightly changed the proportions of the other minerals to come up with a "best-guess" sample (Table 1). The DSC/EGA curves for the "best guess" sample derived from the TEGA-EQM are shown in Figure 2. The EGA of the "best guess"

sample was very similar to the TDL signatures for the unknown sample. Once the TEGA team submitted the "best guess" sample as a possible candidate for the geologic unknown, the team was informed of its chemical and mineralogical properties. The unknown was British Chemical Standard, Lincolnshire iron ore (BCS No. 301/1), which consisted of siderite, calcite, poorly-crystalline goethite, and quartz. Interestingly, the TEGA team suggested that the geologic unknown also contained a 1:1 phyllosilicate (e.g., kaolinite) based upon the dehydration event that begins around 470°C. After detailed mineralogical analysis of the unknown sample (X-ray diffraction analysis of clay-sized fraction), a 1:1 phyllosilicate (probably kaolinite) was detected (XRD peak at 0.7 nm), which apparently was not identified when the chemical standard was originally characterized.

The EGA signatures are quite similar between the unknown and best guess samples (Table 2). The two dehydration events are assigned to the dehydroxylation of goethite and kaolinite with onset temperatures around 200-210°C and 470°C, respectively. The two decarbonation peaks with onset temperatures near 450-480°C and 685-705°C were assigned to siderite and calcite, respectively. The DSC signatures for the unknown and best guess sample have quite different shapes; however, the endothermic response to the decarbonation of calcite is evident in the DSC with an onset temperature just above 700°C.

TEGA and Future Mars Missions: These tests illustrate the outstanding capabilities that a TEGA-like instrument will have on Mars surface missions for detecting and identifying volatile-bearing phases. The TEGA TDL is very sensitive and can detect H_2O amounts down to 10 ppm and CO_2 down to the equivalent abundances of 0.03 %. Therefore, TEGA is uniquely qualified to search for water and CO_2 reservoirs on Mars. Suggested improvements to TEGA for future Mars missions are provided elsewhere in this volume [2].

We anticipate that TEGA or TEGA-like instruments will be instrumental in fulfilling NASA's Space Science Enterprise strategy for Mars of "following the water" as part of a "quest for life." TEGA-like instruments will be needed to determine the abundances of water and other volatiles in the Martian regolith to support long-term human presence on the surface.

References: [1] Boynton, W. V. *et al.* (2000) *J. Geophys. Res., in press.* [2] Boynton, W. V. *et al.* (2000) In *Concepts and Approaches for Mars Exploration,* LPI, Houston, TX, *This Volume.* [3] Lauer, Jr., H. V *et al.* (2000a) In *Lunar & Planet. Sci. XXXI,* Abst. # **1990**, LPI, Houston, TX (CD-ROM). [4] Lauer, Jr., H. V. *et al.* (2000b) In *Lunar & Planet. Sci. XXXI,* Abst. # **2102**, LPI, Houston, TX (CD-ROM). [5] Golden, D. C. *et al.* (1999) In *Lunar & Planet. Sci. XXX,* Abs. # **2027**, LPI, Houston, TX (CD-ROM). [6] Lin, I-C. *et al.* (2000) In *Lunar & Planet. Sci. XXXI,* Abst. # **1417**, LPI, Houston, TX (CD-ROM). [7] Musselwhite, D. S. *et al.* (2000) In *Lunar & Planet. Sci. XXXI,* Abst. # **2044**, LPI, Houston, TX (CD-ROM).

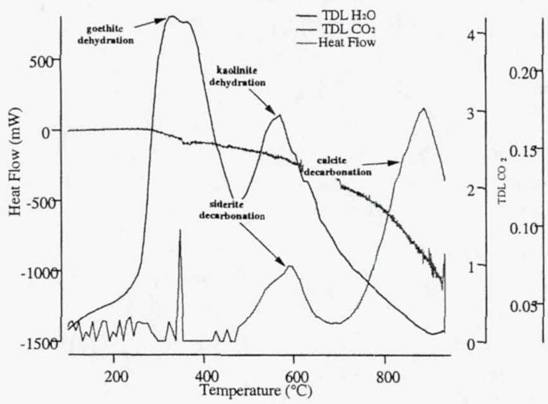

Figure 2. *DSC and EGA for "Best Guess" sample determined by TEGA-EQM.*

Table 1. *Mineral composition of "unknown" and "best guess" samples.*

Geologic Unknown		First Guess Sample		Best Guess Sample	
mineral	wt. %	mineral	wt. %	mineral	wt. %
siderite	12.1	siderite	10	siderite	8
calcite	44.1	calcite	47	calcite	38
1:1 clay	12.5	kaolinite	8	kaolinite	6
goethite	29.1	goethite	35	goethite	28
quartz	2.3			tephra	20

Table 2. *Assignments of temperature features in TDL EGA data for unknown and "best guess" samples.*

Signature	Temperature (°C) Unknown	Best Guess	Assigned Thermal Event
Onset 1st H_2O peak	200	211	goethite dehydroxylation
Onset of 2nd H_2O peak	468	469	kaolinite dehydroxylation
Onset of 1st CO_2 peak	451	480	siderite decomposition
Onset of 2nd CO_2 peak	685	705	calcite decomposition

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Measurements of Water Ice from Martian Orbit and on the Surface

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Cosmic rays are known to produce large number of high-energy neutrons at the Martian surface. These neutrons produce gamma-ray lines from the nucleus either via inelastic scattering (I-type lines), in which they keep their original high energy, or via capturing reactions (C-type lines), in which they are slowed down to epithermal or thermal energies These lines together with the lines produced by natural decay of K, Th and U (N-type lines) will be measured by the Gamma-Ray Spectrometer with high purity Ge detector. The mapping of these lines will allow the investigators to determine the distribution of the principal minerals globally over the Martian surface, which is one of the primarily goals of the Mars Surveyor Orbiter 2001 mission.

The main scientific objectives of Russian High Energy Neutron Detector HEND are consistent with this goal. HEND, as a part of GRS facility, will provide the map of high-energy neutron albedo, which will allow (together with the complementary map of low energy neutron albedo from the Neutron Spectrometer NS) to distinguish I-type, C-type and N-type lines among the forest of lines from the GRS spectrometer.

With the increase of hydrogen content in the surface layer, the termalization path of high energy neutrons is shortened, and the ratio between original high energy neutrons and thermal neutrons decreases. The mapping measurements of this water-sensitive signature is the second main objective of the HEND.

To achieve these goals, HEND has three ^{3}He-based counters of neutrons for energy ranges 0.01 – 1.0 eV, 1.0 – 1000.0 eV and 1.0 – 1000.0 keV with thin, medium and thick moderators, receptively. For the highest energy range of 1.0 – 10.0 MeV HEND has one Stilben-based scintillating detector with active anti-coincidence shielding around it. The HEND data on of neutrons at four energy ranges will be accumulated during the mapping stage of the mission. The deficit of high-energy neutrons in respect to increase of thermal neutrons will be considered, as the observational signature of water rich regions at the surface of Mars. If this signatures will be found for some Martian regions, the models of energy spectra of neutrons will allow to estimate the average amount of ice and to build the contours of water surface density over the region area.

However, the special resolution of orbital mapping will be limited by scale of tens or/and hundred of kilometers, or even worse. The features of the Martian surface have much smaller scale of tens and hundreds of meters, and we may assume that water rich regions contains large number of local spots of ice deposits, which are implemented into the basic surface materials.

We believe that comprehensive studies of these local ice spots may be one of goals of future Mars exploration. The first reason is related with science. The separated spots of ice are very interesting places for surface and subsurface exploration. The shape and size of these ice deposits are very interesting for the theory of surface evolution; the chemical and bio-chemical impurities in water may be the subjects of in-situ scientific analysis. Also, the future sample return mission may take into account the possibility to take some samples of ice for returning collection.

The second reason is related with future technological programs. The large spot of ice is the reservoir of water and the resource of oxygen production. Future mission may be developed taking into account the knowledge about the water ice spots on the Mars.

Therefore, we will discuss the concept of future mission to Mars to search and to measure local spots of water ice in the surface and subsurface layer. We will suggest the instruments for measurements of neutrons at the surface, which will be able to detect the local signatures of water. This instruments will be optimized to measure the differences of fluxes of high-energy neutrons and thermal neutrons at the surface. Also, we will compare different options of moving vehicles, which may carry these instruments, may ensure the small scale mapping of water-reach regions, and may perform the ice sample collection, if necessary.

We will discuss the possible scenario of missions for searching and exploration of subsurface ice water:

At the first stage the orbital remote sensing of gamma-ray lines and neutrons albedo will select the surface regions with presence of ice deposits. This stage will be concluded by the map with surface density contours of ice with resolution of tens-hundreds kilometers. Mars Surveyor Orbiter 2001 will perform this stage.

At the next stage some regions may be selected for lending, and the lander may deliver the movable vehicles to this site. The vehicle will measure the map of the area with size of several kilometers and with special resolution of tens of meters. The separate spots of subsurface ice water could be discovered at this stage.

At the third stage the mission with precision landing capability will be decanted nearby to the selected ice spot for in-situ scientific analysis of water and/or for collection of ice sample for future sample return mission.

Finally, at the fourth stage the sample of water ice could be studied in laboratories for fine analysis of possible signatures of organic.

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DESIGNING A MARS MISSION THAT WILL GENERATE PUBLIC EXCITEMENT AND SUPPORT: SAMPLE RETURN USING *IN SITU* PROPELLANT PRODUCTION. P. J. Mueller, Space Dynamics Laboratory/Utah State University, 1695 N. Research Park Way, North Logan, UT 84341-1947, paul.mueller@sdl.usu.edu.

Introduction: Publicly funded space missions (e.g.all NASA missions) must be perceived by the public as worthwhile in order to retain broad support for NASA and a sustainable space program. In addition, if the public finds the missions exciting and even entertaining, then the level of support will be even greater. "Good Science" alone is not enough to keep the public interested in space. Examples of missions that generated great public enthusiasm and those which were hardly noticed are given. A Mars sample return mission architecture is proposed which will generate much public interest and also provide solid scientific research.

NASA and Its Customers: Too often, NASA seems to think that the space science community is its main customer. Missions are designed around the "best" scientific experiments based on peer review. While scientific merit is important, it is not the only consideration in designing a mission architecture. The ability of the public to become vicariously involved in the mission is also very important. The ultimate expression of this is sending humans to new, unexplored places, and and providing video downlink to bring the experience into our living rooms.

What Makes Missions Interesting or Boring? As just mentioned, the most interesting missions are those where humans are exploring the unexplored. The obvious cases are the early space flights and the Apollo program, especially Apollo 11. Next are robots which can provide a vicarious exploration experience (once again, video is critically important), such as the Sojourner rover driving around and checking out the area around the Pathfinder landing site on Mars, or Voyager zooming by Jupiter and sending back dramatic pictures. Next on the scale is having humans perform interesting tasks in a more routine environment. Examples include manually grabbing a satellite when the shuttle robot arm was unable to snare it, or installing a sunshade over Skylab's outer surface. Robots performing interesting tasks is next, such as building a "robotic colony" on Mars. Then comes using humans to perform routine tasks, including very important scientific experiments. Many Space Shuttle missions come to mind. And lowest on the "interest" scale is using robots or scientific instruments to gather data of a non-visual nature. A good example of this is the probe dropped by the Galileo orbiter into the atmosphere of Jupiter. No dramatic pictures "looking out the window" were available, so the public showed very little interest. Or imagine the Mars Pathfinder web site if there were no pictures were available. It is hard to imagine millions of web site "hits" to see the latest X-ray spectrometry data from one of the rocks, for example.

What Makes a Mars Sample Return Mission Worthwile and Interesting to the Public? Obviously, the idea of bringing back rocks for analysis is inherently interesting. The possibility of finding signs of life (extant or extinct) is also tantalizing. But the concept of demonstrating technologies to be used in future human missions will also be seen as very worthwhile and interesting. In-situ propellant production (ISPP) is seen as innovative and a good way to reduce mission costs for future human missions. But ISPP will probably be more technically challenging and costly than other approaches for a relatively small-scale sample return mission. So a mission using ISPP will probably be later in the program, after the first samples have been returned. So the thrust of the mission will be to demonstrate technologies needed for upcoming human missions, and to use these technologies to bring a sample back to Earth as a bonus. Unfortunately, such a mission does not lend itself well to using video to provide exciting images. The best way to generate interest is to locate the vehicle with a "robotic colony", so that its power and propellant generating equipment can be used for other tasks once the sample-carrying vehicle has launched on its return to Earth. The video would show the robotic colony building up infrastructure from other missions, to become the base of operations for the first human mission.

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THE SEARCH OF CARBONATES IN MARTIAN DUST. L. M. Mukhin, University of Maryland, Department of Physics, College Park MD 20742, USA.

The problem of carbonates budget on Mars still remains as one of the most controversial. Although carbonates of different types are generally believed to be present on Mars surface, there are no successful experiments for their indication. Earth-based spectroscopy gives only upper limit (few %) for calcium carbonate. The Viking experiments were obviously unsuccessful due to low temperature for decomposition of carbonates. Pollak et al. suggested too high concentration of carbonates in airborne dust (1-3%). Meantime the Martian dust should represent the mixture of different minerals formed by wind abrasive. In the first approximation, the mineral composition of the dust should correspond to the average mineral composition of Martian surface. Therefore, the attempt to determine carbonates in samples of the dust from surface looks promising

We propose for future experiments on Martian surface simple, high-sensitive method for determination sorbtion-desorbtion processes of carbon dioxide on the particles of Martian regolith as well as determination of carbonates with level of sensitivity from 10 to 100 ppb. So called method of thermostimulated desorbtion will use the measurement of changing in partial pressure of carbon dioxide during the step heating of the sample. The instrument will consist from dust sampler, pyrolitical cell with temperature range from ambient up to 900-1000C and simple GC. The collection of dust particles should be processed with TV camera control. The total weight of this type of instrument should not be more than 500g.

PHOBOS, DEIMOS MISSION. L. Mukhin, R. Sagdeev, K. Karavasili, and A. Zakharov.

One of primary goals of the Solar System Exploration Program is to determine how planets and small bodies evolved. Phobos and Deimos from a technical point of view are more accessible as the targets for space exploration than most of the small bodies. There is a need to understand the basic scientific nature of the Martian moons, both as representatives of the family of Small Bodies in the Solar System and as components of the Mars planet system. There are a number of key unresolved scientific problems related to the Mars, Phobos, and Deimos (MPD) system. The main one being the problem of origin and evolution of the MPD system, solution of which requires knowledge of the chemical composition of Martian moons, impact history and surface morphology, internal structure etc. This investigation fits into the Mars Exploration Program, as the moons are part of the entire Mars system. Study of the fundamental physical and chemical state of Phobos and Deimos will provide information required for understanding the origin and evolution of the Martian planetary system. In spite of previous efforts, their composition, internal structure and details of the processes, which produce their surface morphology, are poorly understood. Because of this, the models of their origins are not well constrained. Missions to Phobos and Deimos with the appropriate instrumentation would be capable of addressing the unresolved issues.

Thus the main scientific goal of a Phobos/Deimos mission is to study the different characteristics of the Martian satellites, and understand their origin and evolution.

The specific choice of potential missions defines the nature of the experiments.

The scenario for a close by approach to Phobos and Deimos requires the ability of orbital maneuvering in the gravity field of Mars. The net ΔV needed to support such maneuvers is somewhat higher than 1 km/sec and almost independent of whether initial insertion orbit is a standard Mars capture one or approaching Mars with a slow relative velocity from heliocentric orbit.

The main technical concept for the spacecraft is based on using existing electric-powered thrusters as the spacecraft propulsion system for forming spacecraft orbits synchronous with Deimos and Phobos. Preliminary estimates show that the use of such thrusters is compatible with creation of a small, low-cost spacecraft of about ~150 kg, which will include science instruments, having a mass of about ~25 kg. The instrument designs critical for such a scenario have already undergone the development phase (some have even flown on different missions), therefore increasing the feasibility of the suggested scenario and further decreasing the cost of an appropriate mission. Possible mission scenarios imply detailed remote sensing of Phobos and Deimos, and possible landing on Phobos. The spacecraft can operate on Deimos-like and Phobos-like circular Mars orbits synchronized with Deimos' and Phobos' orbital motion. The spacecraft during its synchronous orbiting can fly at altitudes of several km over the surface of Phobos and Deimos. The strategy of minimal altitude flights over Deimos and Phobos would require a more

detailed knowledge of their gravity fields to secure the safe maneuvering under given electric propulsion and final landing on the surface of Phobos and/or Deimos.

The close by remote sensing of Martian moons (while co-orbiting) can provide global coverage data related to both the surface and internal structure of the satellites:

- global geologic mapping,
- size, shape, mass, bulk density,
- color, albedo, photometric scattering and thermal properties,
- mapping of global elemental and mineral composition,
- magnetic properties,
- internal structure,
- Landing site certification and selection.

Operation of the spacecraft in orbits close to Phobos and Deimos provides also a chance to study the respective dust tori (the Martian rings), to study the peculiarities of their orbital motion and libration, and to study the interaction of small bodies with the solar wind.
Direct measurements on Phobos'/Deimos' surface will provide the opportunity to acquire ground truth data needed for validation and interpretation of remote sensing data and to perform a detailed, in situ study of regolith samples:

- elemental and mineral composition,
- volatile content,
- microscopic structure, physical and mechanical properties of the regolith,
- states of magnetization.

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Pgs 2

VISIBLE WAVELENGTH SPECTROSCOPY OF FERRIC MINERALS: A KEY TOOL FOR IDENTIFICATION OF ANCIENT MARTIAN AQUEOUS ENVIRONMENTS. S. L. Murchie[1], J. F. Bell, III[2], and R.V. Morris[3], [1]Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723 (email: scott.murchie@jhuapl.edu); [2]Department of Astronomy, Cornell University, Ithaca, NY 14853 (email: jimbo@marswatch.tn.cornell..edu); [3]NASA / Johnson Space Center, Houston TX 77058 (email: richard.v.morris1 @jsc.nasa.gov).

Introduction: The mineralogic signatures of past aqueous alteration of a basaltic Martian crust may include iron oxides and oxyhydroxides, zeolites, carbonates, phyllosilicates, and silica. The identities, relative abundances, and crystallinities of the phases formed in a particular environment depend on physicochemical conditions. At one extreme, hot spring environments may be characterized by smectite-chlorite to talc-kaolinite silicate assemblages [e.g., 1,2,3], plus crystalline ferric oxides dominated by hematite. However, most environments, including cold springs, pedogenic layers, and ponded surface water, are expected to deposit iron oxides and oxyhydroxides, carbonates, and smectite-dominated phyllosilicates [4,5,6]. A substantial fraction of the ferric iron is expected to occur in nanophase form, with the exact mineralogy strongly influenced by Eh-pH conditions [e.g., 4,7].

Detection of these phases has been an objective of a large body of terrestrial telescopic, Mars orbital, and landed spectral investigations and *in situ* compositional measurements. However, clear identifications of many of these phases is lacking. Neither carbonate nor silica has been unequivocally detected by any method. Although phyllosilicates may occur near the limit of detection by remote sensing [8], in general they appear to occur in only poorly crystalline form. In contrast, compelling evidence for ferric iron minerals has been gathered by recent telescopic investigations, the Imager for Mars Pathfinder (IMP), and the Thermal Emission Spectrometer (TES) on MGS. These data yield two crucial findings. (a) In the global, high spatial resolution TES data set, highly crystalline ferric iron (as coarse-grained "gray" hematite) has been recognized but with only very limited spatial occurrence. (b) Low-resolution telescopic reflectance spectroscopy, very limited orbital reflectance spectroscopy, and landed multispectral imaging provide strong indications that at least two broad classes of ferric iron minerals are commonplace in non-dust covered regions.

"Gray" Hematite: TES results show that nearly all dark, gray regions of Mars (widely interpreted as minimally altered crustal rock) exhibit thermal emission spectra consistent with basaltic to andesitic compositions [9]. The only exception yet found by TES is Sinus Meridiani, whose thermal emission spectrum shows evidence for hematite with such a coarse particle size (>5-10 μm) that its dark, flat visible to near-infrared (NIR) spectrum lacks the diagnostic features of finer-grained, "red" hematite [10]. Both red and gray hematite occur on Mars; the distinction has important implications for past aqueous and thermal environments [10], and accurately making the distinction requires both visible-NIR and thermal IR measurements.

Ferric Minerals in Dark Gray Regions: Visible-NIR telescopic spectroscopy has shown that some dark gray regions exhibit relatively strong absorptions near 660 and 860 nm [e.g., 11]. These regions indicate a greater concentration of finely crystalline ("red") ferric minerals than in the dust (Fig. 1). One of the highest concentrations is in eastern Syrtis Major (arrow, Fig. 1), which was measured at comparable spatial resolution (~20 km/pixel) by the Phobos-2 ISM instrument. That region's spectral properties and the long-term stability of its albedo and color patterns indicate that the crystalline ferric material likely occurs in a stable form, possibly coating basaltic rock [12].

IMP multispectral images also detect the phase having a strong 660-nm absorption (Fig. 2). Its lack of a strong absorption near 530 nm implies a ferric phase other than hematite, perhaps schwertmannite, akaganeite, or goethite or lepidocrocite in nanophase form [13]. Occurrence of the phase is primarily restricted to dust-coated rocks in IMP data [15]. An excellent terrestrial analog is red desert varnish, in which windblown soil is cemented to rocks by recrystallization of ferric iron in the presence of liquid water [15].

Ferric Minerals in Dark Red Regions: NIR spectra from ISM show that dark red regions are distinctive spectrally from dark gray and bright red regions. They are strongly ferric, with a 0.9-μm band deeper and offset to longer wavelengths than in dust, suggesting a different mineralogy [16]. Analogous materials occur at the Pathfinder landing site [17,18]. Spectrally, in the NIR they are consistent with ISM measurements of dark red soils, but they lack the 660-nm absorption characterizing the phase in the rock coatings. Possible ferric phases in the dark red soil are maghemite and ferrihydrite [13,17,18], although interpretations involving a both a ferrous mineral and nanophase ferric oxide are also possible.

Summary: Visible-NIR spectroscopy has detected two classes of ferric iron spectral signatures distinct from dust. Phases consistent with the data mostly require water for their formation. Unlike coarse-grained hematite, these materials have not yet been detected at thermal wavelengths, possibly due to very fine particle sizes. Thus, a key part of the mineralogic signature of past aqueous environments probably occurs as poorly crystalline ferric minerals. Visible-NIR reflectance spectroscopy is a proven tool for detecting such materials, and is therefore an essential part of an effective strategy for identifying ancient aqueous deposits.

VISIBLE-WAVELENGTH SPECTROSCOPY OF Fe MINERALS: S. L. Murchie, J.F. Bell III, and R.V. Morris

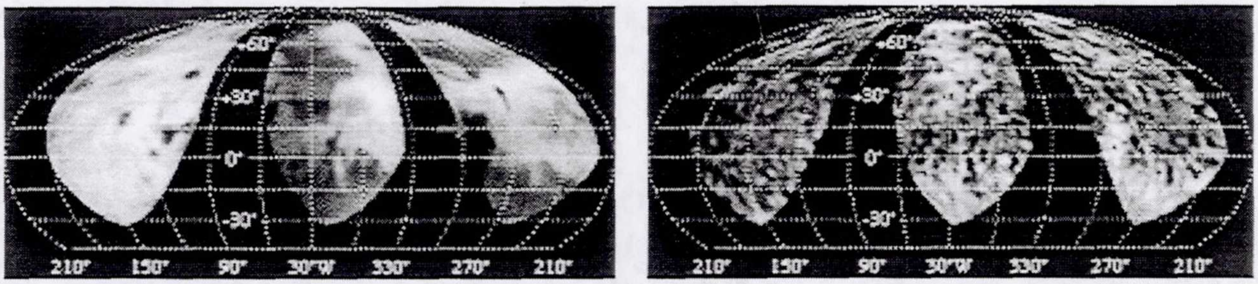

Fig. 1. Map-projected products derived from HST imaging of Mars [9]. Arrow marks eastern Syrtis Major. Left: 673/410 nm ratio. Areas with lesser dust cover appear dark. Right: 860-nm ferric band depth. Stronger bands appear brighter. Note that the strongest bands appear in areas with little dust.

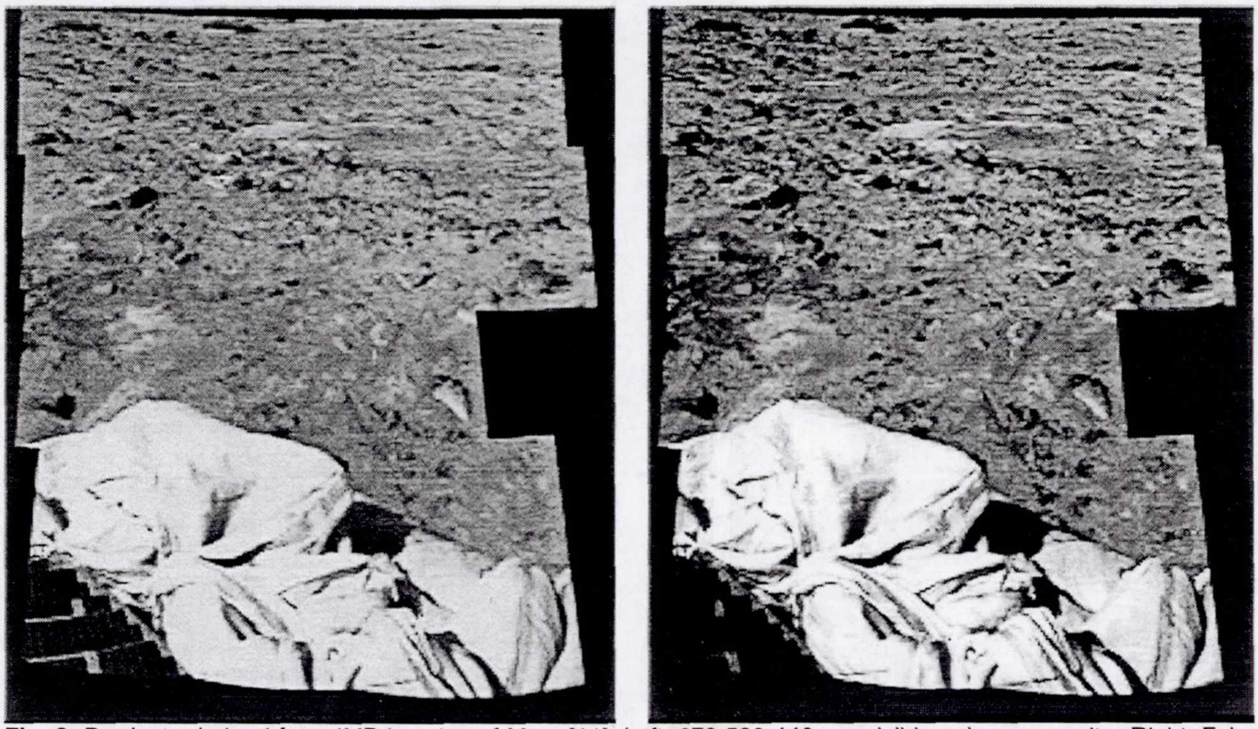

Fig. 2. Products derived from IMP imaging of Mars [11]. Left: 670-530-440 nm visible color composite. Right: False color representation of strength of 660-nm ferric band. Stronger bands appear in redder hues. Not that stronger bands are confined to coated rocks and are absent from dust and soil.

Fig. 3. Spectrum of dark red soil at the Pathfinder landing site compared with the most similar mineral analogs.

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ABS ONLY Pgs 2

ROBOTIC OUTPOSTS: THE MISSING LINK IN MARS EXPLORATION PLANNING. B. Murray[1] and L. Friedman[2], [1]California Institute of Technology, 1200 E. California Blvd., 150-21, Pasadena, CA 91125, (626) 395-3780, bcm@caltech.edu, [2]The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106, (626) 793-5100, tps.ldf@planetary.org.

The emerging opportunity: Mars Exploration is a long-term endeavor--many presidencies, 15+ Congresses. It needs frequent self-renewing milestones and annually affordable budgets, sustained by a widely shared vision of a human future on Mars. However, there is currently no well-defined transition, which can be visualized, from the planned robotic program to an anticipated, but not yet authorized program, to achieve the first human presence.

The robotic and human programs can be joined physically and geographically through the establishment of one or more Mars Outposts, robotic research sites that become certified and equipped landing sites for subsequent crewed flights. The implementation of such Outposts linking human and robotic exploration would provide major and affordable milestones on the popular road to Mars. It could increase NASA's confidence and innovation in Mars exploration.

Lessons from the past: Apollo provided unique experience with human landing on an alien surface, but may not be the most appropriate analogy overall. Early Antarctic exploration required long sailing voyages and traversing the seasonal pack ice. Endeavors required years, not weeks. Best available technology (such as using arctic sled dogs and ski) was the norm. The IGY and subsequent phases were enabled by air and sea transportation originally surplus from WW2, not by special, expensive development programs. More than half a century transpired from the turn of the century "Race to the South Pole" to the establishment of a continually manned base at the South Pole. This transition was accompanied by an evolution from an early nationalistic, symbolic phase to the current international, science-driven phase.

Applications to Mars exploration: Using Antarctica as a template, Mars exploration could easily comprise much of a century reaching the milestone of first human presence and, like Antarctic exploration, can be expected to ebb and flow with trends and traumas on Earth. WW1 ended the first phase of Antarctic exploration and WW2 enabled the more recent one. Mars exploration efforts should be structured to be adaptable to both unexpected opportunities and to disappointing delays. Gradual buildup of Outposts can provide this flexibility.

The Apollo program developed much new space technology. In contrast, Mars exploration most likely will have to rely to a much larger extent on adapting existing space technology to the special Martian needs. Where unique new technology is essential, such as in-situ propellant production, compact nuclear power sources and long-duration human flight away from Earth, it will have to be developed incrementally, avoiding excessive annual funding requirements and inflexible schedules. High initial cost profiles have been a chief inhibitor to the start of a human Mars program. The Outpost can contribute to this incremental buildup by providing test results and small-scale, lower cost applications in support of robotic exploration long before such special martian systems are used by humans.

A human Mars goal is usually recognized as a benchmark post-Space Station international endeavor. International participation is likely to be necessary for the broad, enduring political support the goal requires. Thus, the Mars Outpost concept should be viewed in an international context from the beginning. By building in a step-wise and small-scale manner, many nations can contribute. The Outpost can be an effective means to build a robust international partnership, one not dependent on single programmatic decisions.

Help from the future - the information technology explosion: In contrast to relatively static human capabilities, the power of human-assisting tools is increasing rapidly, especially those exploiting the information technology revolution. Moore's law applies generally to communications, computing, robotics, input/output, artificial intelligence, visualization, and simulation. We have thousands of times more information technology capability available to support space flight now than during Apollo. We can also expect to have yet hundreds of times more by the time of the first human flights to Mars. Modern society is rushing into an unprecedented interactive and information-rich world. Mars exploration must somehow exploit that environment and capability if it is to be affordable and popular. Information technology somehow must be exploited to make going to Mars much less costly than Apollo was.

We must define carefully the intrinsic role of humans immersed within the complex human/machine symbiosis of the future. What are the unique human capabilities essential for Mars exploration? How can they be enhanced by new information technology?

How can non-essential tasks be handled autonomously? Virtual reality, both locally and globally on Mars, may be especially important. Mobile robotic surveillance and continuous wireless communication between all surface units at an Outpost and elsewhere on Mars may also be important. What is especially important to today's Mars planning, is that developing these capabilities serves the robotic program and the human program equally well.

Basic engineering functions must be evaluated with an eye to miniaturization and to autonomy. The Mars Outpost infrastructure needn't necessarily be "human-scale" in order to prepare for meeting human needs. Miniaturized and autonomous infrastructure needn't wait until the humans arrive to start functioning. Better that such subsystems be developed incrementally, tested and directed to carry out increasing DIFFICULT robotic science tasks in stages. But the early design process requires a vision of the entire exploration process, at least up through human occupancy of one or more Mars Outposts.

Possible scientific attributes of Mars Outposts: The initial, distributed infrastructure of the bases connected by robust wireless communications might include long-lived elements such as: (1) Earth and Mars communication system; (2) high-capacity computing and data storage; (3) navigation and surveillance system; (4) continuous virtual reality capability widely available on Earth; (5) in-situ production and storage of propellant, and breathing oxygen; (6) environmental monitoring systems, including radiation, dust, and surface wind monitoring; and (7) long-lived robotic scientific observational systems. In the longer term, the Outposts could augment the capability now envisioned by the robotic program. The Outposts would make good sites for conducting (1) wide band, long duration seismometry; (2) deep (and therefore long-duration) solar powered autonomous drilling with in-situ examination and/or sample return; (3) long-term magnetotelluric studies; (4) long-term robotic traversing and tele-operation, (5) planetary dynamical studies using the long-duration radio direct link; and (6) autonomous launching of scientific balloons and airplanes.

New requirements for the current Mars program: There will be new requirements as well as new opportunities to prepare for the long haul and also to engage sustained human interest in the robotic program as an essential precursor to human involvement. Current Mars exploration planning should be charged with: (1) establishing the physical, topographic and geographic requirements for an integrated robotic/human base (this could include surveys for ground ice at low latitude sites for eventual human use as well as FOR nearer-term scientific exploitation); (2) defining the various possible technical forms of future human occupancy, ranging from the "large, mostly closely-spaced in time" to a "smaller, extended" with more deliberate buildup of infrastructure, in order to better establish the physical requirements for future outposts; and (3) developing an integrated base architecture and initiating key long-term developments such as in-situ resource utilization and autonomous communication and computation infrastructure.

Conclusions: It is important that near-term robotic exploration take place within a grander, public vision stretching out through the eventual human presence on Mars. Definition and targeting of specific sites on Mars as first robotic, and eventually candidate human bases, is valuable and affordable within the context of the robotic program alone, yet can greatly expand the popular interest and significance of that program. The program otherwise lacks a natural climax or defining accomplishment which is widely supported by scientists and the public alike.

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The Athena Miniature Rock Coring & Rock Core Acquisition and Transfer System (Mini-Corer). T. M. Myrick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, myrick@hbrobotics.com), S.P. Gorevan, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, gorevan@hbrobotics.com), C. Batting, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, batting@hbrobotics.com),S. Stroescu, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sergiu@hbrobotics.com), J. Ji , (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, chunlei@hbrobotics.com), M. Maksymuk, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, mike@hbrobotics.com), K.R. Davis, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, krdavis@hbrobotics.com) M.A. Ummy, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, ummy@hbrobotics.com), and the Athena Science Team.

Introduction: The miniature rock coring and rock core acquisition and transfer system (Mini-Corer) is a part of the Athena Mars rover science payload. Its major objective is to acquire rock cores for in-situ examination by other instruments of the Athena instrument suite and to provide for a precision caching of the acquired cores for purposes of sample return. The Mini-Corer is a highly developed robotic drill capable of obtaining two 25-mm long and 8-mm diameter cores from the same hole from very strong rocks. The low power Mini-Corer can readily drill 25 mm into strong basalt[1] in less than 6 minutes while consuming less than 10 watt-hours of power. A key feature of the Mini-Corer is its ability to break off the core from the base rock and retain the core. A pushrod internal to the core tube provides for a controlled and positive ejection of the core. This same pushrod is used to stabilize the target rock during the initial coring action. With the autonomous acquisition of a specialized tool, the Mini-Corer also acquires and transfers unconsolidated soil to the return cache. The Mini-Corer employs 5 brushed DC motors equipped with incremental encoders.

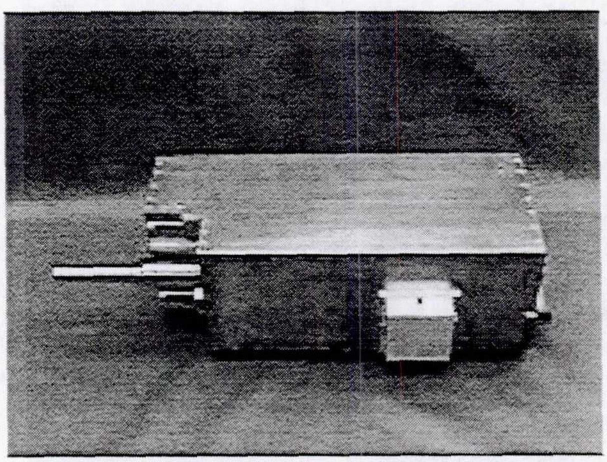

Figure 1: The Engineering Model of the Athena Mini-Corer.

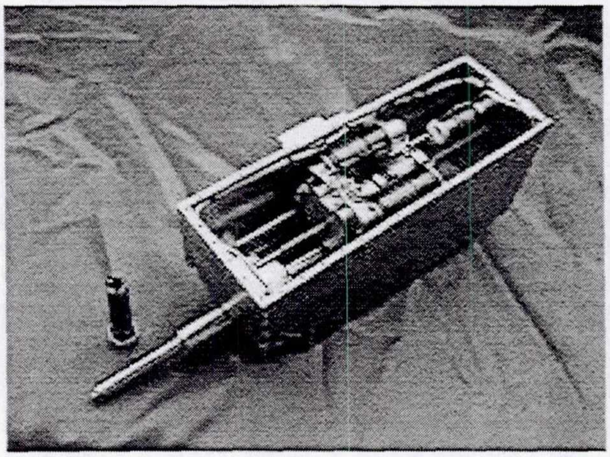

Figure 2. The interior of the Athena Mini-Corer

Initial Entry; Stabilizing The Target Rock With the Pushrod: To facilitate reliable autonomous drilling into small rocks or rocks with an unstable set position and to prevent drill bit "walking" upon initial entry, the internal push rod is used. The pushrod is lowered via the mini-corer z-axis and its own miniature lead screw to make initial contact with the target rock. A thrust force sensor indicates rock contact and the push rod maintains a stabilizing force of about 22 newtons in the direction of drilling. The rotating core tube with its cutting teeth is lowered to the rock surface with the z-axis and commences to cut the rock surface. As the core barrel descends into the rock the pushrod retreats into the Mini-Corer body by the same distance. This synchronous action of the push rod and core tube continues until the core tube tip has acquired a secure bite into the rock.

Breaking off the Core from the Base Rock and Acquisition of the Core: Drilling continues until the desired core length has been reached (depth information is provided by incremental encoders on the z axis drive train). At this point, the core break-off tube begins to rotate to the break-off position. The core tube and the break-off tube are coaxial during drilling. For breakoff, the break-off tube rotates relative to the core tube. With this relative rotation, the two tubes are no longer coaxial. This action shears the core off

from the base rock. The relative position of the tubes creates a lip that provides for a positive retention inside the core tube of the broken-off core.

Core Transfer: The Mini-Corer is optimally mounted on the rover such that it can be actuated in both pitch and translation axes. These two axes in conjunction with the z axis of the Mini-Corer can be called upon to position the tip of the Mini-Corer to a core storage location (cache) or in a convenient position for examination of the core tip by the Athena instrument heads mounted on the rover's instrument arm. Once lined up with the core storage location, the break-off tube is commanded to rotate to its original position. The pushrod is then moved to the core ejection position and the core is precisely ejected out of the core tube.

Drill Algorithm: The basic drilling algorithm is based on thrust and torque thresholds. As drilling proceeds normally through the rock, a torque threshold is monitored by the controller. If the torque is sensed to be higher than the threshold, the z-axis retreats a very small amount. The retreat of the drill tip from the rock face reduces the torque. Once the torque drops below the threshold, the z-axis moves toward the rock and cuts more rock until the torque threshold is encountered again and the drilling loop is repeated. If the torque threshold is not encountered, drilling continues until the targeted drilling depth is reached. A thrust threshold is monitored to prevent too much thrust (which might present a risk to the rover) from being reacted into the mini-corer platform.

Science Return from Drill Sensors: Mini-Corer sensor data required for the drilling algorithm generate a signature that correlates with some physical characteristics of the target rock. Torque, thrust and penetration rate data can be inverted and compared to drill performance in terrestrial analogs to arrive at a determination of rock compressive strength and density.

Drill Bits: The cutting teeth on the tip of the Mini-Corer are especially designed to cut into strong rock with a minimum of torque. Currently the teeth in use by the Mini-Corer are made of tungsten carbide. Testing indicates that 8 mm carbide drill tips start to dull after drilling ten 30-mm cores into a basalt with a compressive strength of over 100 Mpa but these bits are still useful. In conjunction with DeBeers, Honeybee Robotics is developing a very long lasting PCD and natural diamond drill tip.

Autonomous Changeout of Drill Bits: The nominal performance goal of the Mini-Corer is to acquire forty 25-mm rock cores with the same drill bit. Should the target rocks be hard enough to dull the bit before 40 cores are acquired, the Mini-Corer is designed with a quick-change bit acquisition capability. Using the z, breakoff and push rod axes, a dull bit is removed from the Mini-Corer tip and a new drill bit is acquired in a make-before-break robotic transfer.

Soil: Employing the same quick-change subsystem used for changing drillbits, the Mini-Corer drill can be commanded to acquire a soil acquisition end effector. This gripper utilizes the pushrod and drill drive train for its operation; no additional actuators are requireed.

Instrument Performance: A 5 mm breadboard version of the Mini-Corer has been successfully field tested aboard JPL's FIDO rover and the 8-mm Athena Mini-Corer is very close to being flight ready. The first 8-mm engineering model Mini-Corer is nearing complete assembly as this abstract is being written. In the last year drill bit design and drilling algorithm advances have reduced power consumption by a factor of five. The Mini-Corer mass is 2.7 kg and the Mini-Corer box dimensions are 29.8 cm x 14.51 cm x 9.64 cm.

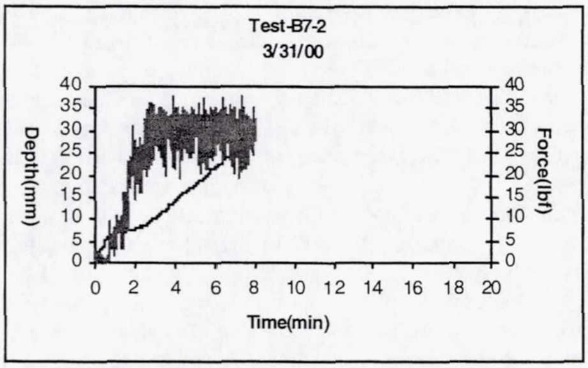

Figure 3 8-mm Drilling into Basalt[2]

References: [1] [2] A Hydrothermally altered quartz tholeiite from the Keweenawan Volcanic Group from the North Shore of Lake Superior. The rock was analyzed as part of the Ph.D. thesis of Joyce Brannon (1984) "Geochemistry of Successive Lava Flows of the Keweenawan North Shore Volcanic Group," Washington University, St. Louis.

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RECOMMENDATIONS FOR PRESERVING THE INTEGRITY OF SAMPLES COLLECTED ON MARS AND RETURNED TO EARTH FOR ANALYSIS. C.R. Neal[1], B.L. Jolliff[2], J.J. Papike[3], G. MacPherson[4]. 1: (neal.1@nd.edu) Dept. Civil Eng. & Geological Sciences, Univ. Notre Dame, Notre Dame, IN 46556; 2: Washington Univ., St. Louis, 3: Institute of Meteoritics, Univ. New Mexico; 4: Smithsonian Institution, Washington DC.

Introduction: As part of an integrated approach to planetary exploration [1], samples will ultimately be returned from Mars to Earth for analysis. This will be the next logical step in our exploration of the red planet as we strive to learn more about its evolution and investigate the possible occurrence of life on Mars. NASA'a Curation and Analysis Planning Team for Extraterrestrial Materials (CAPTEM) has been studying the preservation issues for returning geological samples from Mars [2,3]. The overriding goal of these studies has been the preservation of pristine Martian signatures in the returned samples, thus maximizing the scientific value of such missions. Preventing contamination/alteration is particularly critical for chemical, biological, and morphological signatures that are indicative of life, either extinct of extant. Such prevention is required for the short term during collection, transport, and re-entry & impact on Earth, as well as for long term curation. In this presentation, we discuss contamination issues within the framework of an Athena-like sampling mission; however, the concepts may be extrapolated to other plausible sampling scenarios. Issues encompassing preservation from the successful collection, to return to Earth, and curation of martian samples are discussed within this framework. We build upon earlier reports [e.g., 4-7], and complement(?) the recent MSHARP report [8] by concentrating -on the samples themselves. Below is a summary of recommendations made by CAPTEM that will maximize the scientific value of any returned Martian samples. These recommendations are made, for the most part, with consideration of the stringent budgetary constraints that will be part of any sample return mission to Mars.

The governing principle behind this study is that any procedure or piece of equipment that can impact (contaminate) the Mars samples during collection, transportation, or curation needs to be fully evaluated through analysis and experimentation ***prior*** to implementation by a scientific committee, that has expertise in extraterrestrial sample analysis, curation, and preservation.

Spacecraft: Transportation of organic material from Earth to Mars could result in bio-organic contamination of the returned samples resulting in "false positives" when the samples are examined for signs of life. In turn, this may cause unnecessary delays in releasing the samples to the scientific community. Therefore, the spacecraft cannot just be sterilized, but the dead bacteria, etc., need to be removed.

Sample Collection: Contamination of samples is possible from contact with any rover components, ranging from *in-situ* analytical instruments to the wheels, and contact with parts of drilling or caching mechanisms. For rock coring, tungsten carbide will likely be used for the drill bit as it is the best material for this endeavor. CAPTEM endorses the use of a coring system to acquire fresh, unweathered samples. However, of all the potential sources of contamination during sample collection, contamination from a coring device is likely to be geochemically the most severe(?). Contamination of the samples via the drill bit could potentially compromise trace element (e.g., Zr, Nb, Hf, W, C, platinum group element) and isotopic (e.g., W-Hf, Lu-Hf, Re-Os, Pt-Os) analyses.

Assuming a coring device is used, each rock selected for sampling should have multiple cores extracted (5-10 g per rock). Although essential geoscience studies on most individual rocks **can** be done with fine-grained samples as small as 5 grams, a larger sample mass is desirable for coarse-grained rocks. Even for fine-grained rocks, 5 grams will leave little or no reserve material for future studies. It is estimated that a minimum of approximately 10% of each sample (0.5-1 gram) will be required for planetary protection studies. 1-2 g of material is desirable for determinations of trace organic constituents. Therefore, while we accept 5 grams per rock as a minimum mass, we urge where possible to exceed this mass up to a total of ~10 grams or equivalent to 4 cores per rock.

The Samples: A diverse suite of samples should be returned in order to conduct broad-based investigations into the evolution of Mars [2]. If analyses are to be conducted on Earth, it is highly desirable that these samples be preserved in their pristine condition during collection, travel back to Earth, and analysis/curation.

Sample Containment: As the samples will be contained for a relatively long period, the container should not compromise sample integrity. In addition, temperature control will be important for preserving sensitive biologic/chemical signatures. If Teflon is to be used, it should be PFA or FEP and applied as a baked-on coat to the metal of the sample container, rather than a separate insert. This protocol reduces the number of parts to be manipulated, and the possibility that the sleeve could come loose, preventing sample insertion, is avoided. Mixing of samples is considered undesirable especially if a petrologically diverse suite of samples is returned from different areas around the landing site(s).

Materials: A clear understanding of how any drill will operate, along with any sample contamination problems, should be acquired through extensive testing of such a drilling system prior to assembly of the spacecraft. As far as possible within mission/curation constraints, only *pure, homogeneous* materials should be used for components that come into contact with the samples. Materials that would be acceptable from a sample contamination standpoint are:

- Low-Zn aluminum (i.e., not the 7000 series alloys) - the 6061 alloys (i.e., alloyed with Mg and Si) are acceptable;
- Low sulfur stainless steel that contains no molybdenum and is compatible with electropolishing and passivating in nitric acid;
- Titanium alloys should be as pure as feasible given the required physical and metallurgical properties;

- Unplasticized Teflon that would impart organic contamination recognizable as non-biogenic;
- Tungsten carbide used for the drill bits should be pure WC and sample contamination documented through drilling experiments on Earth.

Such materials should be analyzed for organic and inorganic constituents using at least two different analytical techniques. This will either demonstrate the purity of the substance or allow an understanding of the nature of potential contamination through quantifying the impurities present.

Sterilization: While the probability of the returned samples containing viable organisms cannot be demonstrated to be zero, it is considered to be extremely low [7,9,10]. We suggest that if a sample contains no organically bound carbon or demonstrably viable organisms, it be released for scientific study. If sterilization is required, we recommend that heat and chemicals NOT be used as these methods severely compromise sample integrity; at present, the preferred sterilization method is high-dose gamma radiation [11].

Curation: Long term curation of martian samples on Earth will utilize procedures and protocols developed for lunar samples, cosmic dust, and meteorites that will preserve the integrity and pristinity of returned samples. However, protocols need to be reviewed and modified to meet the challenges of curating samples in the long term. For example, storage of the samples should be ~240 K and under an inert atmosphere (e.g., nitrogen) for long term preservation of low-temperature chemical signatures and prevention of isotopic exchange. The need to keep bio-organic contamination out of the sample containers and the curation facility will require an examination of air filtration requirements and protocols.

RECOMMENDATIONS: The following is a list of CAPTEM recommendations for ensuring the pristinity of returned Mars samples (see [2,3]):

The spacecraft needs to be sterilized and cleaned at least to Pathfinder standards, with the components that come into contact with the samples having a higher degree of cleanliness. Use of witness plates for this endeavor is essential, as they could prove to be useful in documenting forward contamination.

Drill-bit contamination needs to be thoroughly investigated through experiments and component analysis on Earth; the composition of the drill bits should be characterized with detailed chemical and isotopic analysis. This should also be applied to any lander-based regolith/rock drill.

A variety of sample gathering devices e.g., scoop, drills) should be flown on the rover and lander to allow the collection of a diverse suite of samples and, most importantly, to enable the return of samples if any one sample collection system fails.

The sample caching container should be constructed out of the purest materials possible, allow for no cross contamination between potentially diverse samples, keep rock cores separate from each other and from unconsolidated regolith samples, and be sealed on the surface of Mars.

Regolith core from any lander-mounted drill be kept separate from the rover regolith sample(s) thief the former are contaminated with and disturbed by rocket exhaust.

The temperature of samples be kept at, or ideally below 240K.

There should be no artificial tracer placed in the drill bit because the deliberate contamination by the addition of tracers will interfere with data interpretation.

Only the purest of materials should be used for components coming into contact with the samples. Materials used in spacecraft construction (i.e., those that will come into contact with the samples) should be fully characterized and a database created during the manufacturing stage of the components (whether for spacecraft or the receiving/curation facility).

The preferred sterilization method is high dose gamma radiation as it will have little impact on the chemical or morphological signatures of the samples.

We recommend that a thorough review of curatorial procedures and protocols be conducted (and amended accordingly), prior to the return of the samples, and new protocols formulated to address the unique challenges of long term martian sample curation/preservation.

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IN-SITU MEASUREMENTS OF COSMOGENIC RADIONUCLIDES ON THE SURFACE OF MARS.

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Introduction: Cosmogenic nuclides are produced by cosmic-ray nuclear interactions with target nuclei in rocks, soils, ice, and the atmosphere. Cosmogenic nuclides have been widely used for investigation of solar system matter for several decades [1]. Stable nuclides, such as ^{3}He, ^{21}Ne, and ^{38}Ar, are built up over time as the surface is exposed to cosmic rays. The concentrations of cosmogenic radionuclides, such as ^{10}Be (half-life=1.5 Myr), ^{26}Al (0.705 Myr), and ^{14}C (5,730 yr) also build up with exposure time but reach saturation values after several half-lives.

Especially after development of accelerator mass spectrometry (AMS), cosmogenic nuclides in terrestrial samples are routinely used for geomorphic studies such as glaciation, surface erosion, and tectonics, and studies of atmospheric and ocean circulation [2]. Cosmogenic nuclides on Mars will be able to answer questions of exposure ages, erosion rates, tectonic events, and deposition rates of sediments and/or volatiles. The concentrations of cosmogenic stable nuclides gives the integrated exposure time of the rock/mineral, and the activities of radionuclides give recent records for times back as long as a few half-lives.

Cosmogenic Nuclides on Mars: Unlike on the Earth, the cosmic rays readily reach the Martian surface because of its thin (~15 g/cm^2) atmosphere and very weak magnetic fields. The cosmogenic nuclide production rate and profiles in the Martian surface are similar to those on the Moon, even after taking into account the average Martian atmospheric depth of 15 g/cm^2 [3]. The production rates of various cosmogenic nuclides on Mars can be calculated using LAHET Code System that has been well tested using a database of cosmogenic-nuclide observations in lunar, meteoritic, and terrestrial samples. Because the production rates on Mars are 3 orders of magnitude higher than those on the Earth's surface, at levels like those in meteorites and lunar samples, many cosmogenic nuclides can be measured in Martian surface features.

Although production rates of nuclides on the Martian surface are similar to those in extraterrestrial materials, the application of cosmogenic nuclides are somewhat similar to terrestrial applications [4]. The terrestrial applications of cosmogenic nuclides have included erosion and exposure histories (by glaciation, floods, landslides, faults), ages of impact craters, deposition or ablation of soils and icecaps, and ages of young volcanic eruptions. Steady state erosion of bedrock surfaces may give information on long-term erosion rates of the Martian surface. The histories of aeolian dust and layered terrains near the poles can also be studied. The use of multiple cosmogenic nuclides is required to constrain exposure histories of Martian surface samples.

The promising nuclides for up to 10^{6}-10^{7} years of histories on Mars (^{14}C, ^{36}Cl, ^{26}Al, ^{10}Be, ^{53}Mn, ^{3}He, and ^{21}Ne) are those often used to study other extraterrestrial materials. The ^{10}Be-^{26}Al-^{21}Ne combination is very good for solving complex histories of terrestrial surface morphologies as well as histories of meteorites. However, all of these cosmogenic nuclides can be measured only in returned samples at the present detection methods.

The radionuclide ^{14}C made in the Martian atmosphere has been proposed to study the nature of atmosphere-regolith interactions [5]. However, the Martian atmosphere is so thin that production of ^{14}C in soil nitrogen could be a serious complication [6]. Some cosmogenic radionuclides made in the Martian atmosphere could be deposited on the surface, as is the case for terrestrial cosmogenic nuclides.

The global surface chemical composition of Mars can be mapped by orbital gamma-ray measurements [7], and a Ge gamma-ray spectrometer is scheduled to fly on the Mars 2001 orbiter. However, the gamma-ray flux is dominated by prompt gamma rays, with decay gamma rays generally having much weaker fluxes.

Detection of Cosmogenic Radionuclides on the Surface of Mars: Because the production rates of cosmogenic nuclides on Mars are high, the activities of some cosmogenic radionuclides can be detectable on the surface of Mars. An excellent candidate is ^{26}Al, but other nuclides, such as ^{22}Na (half-life=2.61 yr), ^{54}Mn (312 d), ^{60}Co (5.27 yr), as well as ^{40}K and the U-Th decay chains can be measured.

However, the high cosmic-ray intensity increases detector background levels. This requires massive shielding for detectors or coincidence and/or anti-coincidence counting systems. However, massive shielding is not practical on the surface of Mars except by putting detector systems into deep cores or tunnels.

The γ-γ coincidence method is a good technique for the detection of several important radionuclides. The coincidence can be obtained with two gamma-ray detectors in order to reduce background level. For ^{26}Al measurements, using the 0.511 MeV-1.809 MeV coin-

cidence eliminates the interference of $^{26}Mg^*$ prompt γ rays of 1.809 MeV in addition to the reduction of background. For ^{22}Na measurements, the 0.511 MeV-1.275 MeV coincidence can be used.

^{22}Na-^{26}Al pair: Both nuclides are produced similar nuclear reactions. The ratio and activities of two nuclides will tell us recent geometry and histories. ^{22}Na can give the sample's geometry during the last 5 years and the prediction of the ^{26}Al production rate at that location. ^{26}Al can be used to determine the exposure time at the location or average shielding depth or gardening rate of regolith samples. Further more, combining of ^{22}Na-^{26}Al and proposed *in-situ* noble gas measurement (^{21}Ne) in the same sample would provide both erosion rate and exposure age.

The gamma-ray spectrometer used to measure cosmogenic nuclides could simultaneously be used to determine the surface's elemental composition. Unlike an orbital gamma-ray spectrometer, which detects individual gamma rays [7], our surface system would use gamma rays in coincidence. Gamma-ray pairs (energies in MeV) that could be used to measure elements include: 2.741-6.129 for O, 1.369-2.754 for Mg, 4.934-3.539 for Si, any two of the 5.421-2.380-0.841 cascade for S, any two of the 6.111-0.517-1.951 cascade for Cl, 6.419-1.943 for Ca, 6.760-1.382 for Ti, and 5.920-1.725 for Fe.

The γ-ray detector system can be also used for *in-situ* instrumental neutron activation analysis using a ^{252}Cf or other removable intense source of low-energy neutrons.

There are some technical problems in using germanium gamma-ray detectors. The Ge detectors would have to be cooled to ~100 K when they are used. A passive radiator, like that proposed for a Ge gamma-ray spectrometer on a Rosetta comet lander [8], could be used at night. Operation of Ge detectors would be easier in winter or near the Martian poles. Radiation damage is a problem with Ge detectors, and the ability to anneal the Ge detectors might be needed. The weight and power for a Ge gamma-ray detector system might be fairly high.

Another good detector system for Martian surface gamma-ray measurements could be made using CdZnTe room-temperature solid-state detectors [9]. While the energy resolution is not as good as Ge, it is good enough (about 2%) for use in a coincidence system and would be lighter and more compact.

Conclusion: The measurement of multiple cosmogenic nuclides is required to understand surficial histories of Mars. The high cosmogenic nuclide production rates on Mars allow us to use multiple nuclides as in studies of terrestrial samples, meteorites, and lunar samples. Although sample return is extremely important for such studies, we feel that *in-situ* gamma-ray measurements of cosmogenic nuclides on Mars during future missions can provide valuable information about the history of the Martian surface.

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Colliding Beam Fusion Electric Power System for Mars Exploration. Joseph A. O'Toole[1], Frank J. Wessel[2], N. Rostoker[2], and M. Binderbauer[2], [1]Los Alamos National Laboratory, 1663 Bikini Atoll Road, MS H805, Los Alamos, 87545, [2]University of California, Department of Physics and Astronomy, Irvine, CA 92697-4575.

Introduction: Exploration of Mars, by robotic means and eventually manned exploration, will require significant levels of reliable, high-density electric power. An electric power system based on fusion energy possesses distinct advantages. If developed successfully fusion energy sources would be characterized by high fuel energy density, low system mass, modest fuel requirements, and the abundance of fuel sources throughout the solar system. NASA plans a FY01 new program start with a goal of realizing a fully operational fusion space propulsion system within 20 years; a similar time frame as envisioned for the MARS Exploration Initiative. The development milestones for a planetary-based power system and space propulsion system are synergistic extensions of our existing efforts to develop an Earth-based energy source. This paper reviews the scientific and technology base for our design and describes options for the use of this technology on a Mars mission.

Near term power for planetary exploration: We begin by considering the Colliding Beam Fusion Reactor (CBFR). [1], [2], [3] In a CBFR the plasma core is confined inside a "high beta" ($\beta \equiv$ plasma pressure / magnetic pressure) magnetic cavity that extends along the axis of the cylindrically symmetric system. Such a compact, high-beta system is characterized by a reversal in the direction of the applied magnetic field, on-axis, and the absence of appreciable magnetic field within the fusion core plasma; it is generally referred to as "field-reversed configuration" (FRC). [4] The plasma in an FRC sustains a large circulating current, hence generating a self-magnetic field that adds to the ambient field. Injected ion beams (E_{ion} ~ 1 MeV) maintain the current and replenish the spent fuel. In the confined-ion frame-of-reference the particle distributions are thermal and the circulating current is unneutralized. The ions orbit size is comparable to the dimensions of the system, hence classical transport of the particles and energy are predicted, reducing the size and mass of the system by many orders of magnitude compared to other fusion concepts. Finally, beam injection enables the use of aneutronic fusion fuels. The reaction product of such fuels are predominantly charged particles that can be collimated efficiently along the axis of the open-ended system, and converted directly to electric energy. The system scales well to low power, and with heavy nuclear shielding not being required, results in a compact, light weight system suitable for deployment.

We have evaluated the confinement physics in a CBFR based on the Vlasov-Maxwell equation, including a Fokker Planck collision operator and all sources and sinks for energy and particle flow. The results indicate that the CBFR could be scalable in the output power range of 10^6-10^9. Most, if not all of the critical technologies needed to demonstrate the CBFR readily exist: superconducting magnets, vacuum systems, beam injectors, etc. Moreover, low energy, pulsed FRCs have already attained parameters close to the range needed for fusion energy. A 50 MW electric power system might involve the following (approximate) design parameters: 1-meter diameter, 7-meters length, magnetic field ~ 7 Tesla, ion beam current ~ 10 A, and fuels of either D-He^3, P-B^{11}, P-Li^6, D-Li^6, etc.

A description of the electric power system and its function will be discussed, along with a development time-scale, followed by some options for its use in Mars explorartion.

The R&D milestones for our Earth energy research program are to complete phase 0 - scientific feasibility, phase 1 – engineering feasibility, and phase 2 – commercial feasibility within a three to six-year period. Appropriate modifications to this schedule would be possible to reflect efforts related to space propulsion /planetary power system testing.

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Mars Exploration Strategies: Forget About Sample Return! D. A. Paige, Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095. dap@thesun.ess.ucla.edu.

Introduction: During the past months, loss of the Mars Climate Orbiter and Mars Polar Lander spacecraft have received considerable attention. In reality, NASA's toll of lost missions during this period has been much higher due to the cancellation of the Mars 2001 lander mission and the failure to plan a credible Mars sample return mission. NASA has commissioned a number of internal and independent investigations which have focused on the technical and management failures that were responsible for the failures of the '98 missions. However, the even more serious setbacks that the future missions in the Mars Surveyor Program are experiencing have not received the same degree of critical attention. In this paper, I attempt to identify some of the key science strategy issues relating to these problems, and suggest returning to a strategy for Mars exploration that is more closely aligned with reason, risk avoidance, and reality.

The Pre-1996 Strategy: In the course of researching this abstract, I read through the various Mars strategy documents that have been produced by NASA, JPL and the National Research Council over the years. One of the most well-reasoned was produced in January 1995 at the request of Michael Meyer of NASA's Exobiological Program Office, and is entitled "An Exobiological Strategy for Mars Exploration". The study advocates dividing the search for past and present life on into a logical sequence consisting of 5 phases, which are:

Phase 1. Global Reconnaissance, focusing on the past and present role of water, and the identification of sites for future, detailed study.

Phase 2. In-Situ Exploration of Promising Sites, focusing on describing their geologic, mineralogic, elemental, and isotopic characteristics, as well as the abundance and distribution of volatile species and organic molecules.

Phase 3. Deployment of Exobiologically-Focused Experiments, to provide detailed characterizations of the population of organic compounds, and to search for biomarkers of formerly living organisms, and extant life.

Phase 4. Robotic Return of Martian Samples to Earth, to improve the characterization of organic compounds, and to verify any evidence for biomarkers and extant life discovered in Phase 3.

Phase 5. Human Missions, providing detailed scientific characterizations of sites of unusual biologic interest, or sites that are inaccessible to robotic exploration.

This report, which was produced before the hoopla associated with the Mars Pathfinder landing and the "Mars Rock Discoveries" in 1996, provides a clear, step-by-step approach to answering the question of whether or not life ever emerged on Mars that takes proper account of our lack of scientific knowledge regarding the planet Mars, the distinct possibility of ambiguous results and interpretations of scientific data, as well as the significant technical challenges, risks and timescales associated Mars exploration. It is not a comprehensive strategy in that it is focused on exobiology and does not thoroughly consider investigations of the solid planet, the atmosphere and climate, and preparation for human exploration. However, it does provides a good model for how to accomplish a high-level scientific goal through a series of missions.

The Post 1996 Strategies: After 1996, the Mars program began attracting considerably more attention than it had in previous years, and I would argue, became a victim of its own success. After 1996, we saw significant increases in a) the level of visibility, interest and participation in the Mars program, b) the level of funding for Mars activities, c) the administrative levels at which planning decisions regarding the Mars program were being made) d) the overall level of naivete regarding scientific and technical issues associated with Mars exploration that was injected into the planning process. For instance, the successful Mars Pathfinder landing was interpreted by many to suggest that even more ambitious surface missions could be accomplished at even lower cost. In retrospect, we now know that the success of Pathfinder was the result of a very shrewd management approach which maintained large margins in all areas, including scientific performance, as well as very careful attention to testing. We now know that anything less thorough than Pathfinder will probably result in a developmental or mission failure. Also, the fact that credible scientists found "evidence for ancient life" in the ALH84001 meteorite was interpreted by some to suggest that such exciting evidence may be much more ubiquitous on the/ surface of Mars than had previously been imagined, and that confirming the ALH84001 discoveries would only be a matter of returning a suitable sample to Earth for detailed analysis. However, in retrospect, we now know that much of the evidence for ancient life found in the "Mars rock" is ambiguous or debatable, and that similar issues are likely to arise when robotically acquired samples are eventually returned to Earth. We also now have a deeper appreciation for the fact that Mars

is a really big place with a complex history to unravel, and that it will take quite a lot of evidence to prove that life ever existed on Mars, or quite a lot of searching to prove that it never did.

During the 1996-2000 period, the incorrect notion that Mars exploration might be "quicker and easier" than thought previously led to a certain degree of impatience with the orderly process of scientific exploration that had been advocated previously. A number of attempts were made to create "leapfrog" architectures in which Phase 4 sample return missions came directly on the heels of Phase 1 global reconnaissance missions, skipping Phase 2 and Phase 3 altogether. The net result of this accelerated approach has led to a series of failed mission concepts for the '01 and '03 opportunities that in total, will probably end up costing the community about four years and on the order of 1 billion dollars.

The Misguided Emphasis on Early Sample Return: One of the most prominent aspects of the failed 1996-2000 exploration architecture plans was to accomplish the goal of sample return at the earliest possible opportunity. One could argue on philosophical grounds that this aggressive approach is in keeping with established pattern of human technological and explorational accomplishments, i.e. that most goals are achieved soon after they are technically feasible, and that the publicly stated justifications for accomplishing these goals often have little to do with reality. For the case of Mars sample return, there has been a strong tendency to equate the analysis of returned samples with "good science", and while it is undoubtedly true that one could do a lot of good science on returned samples, we are a long way from a situation where sample return is *necessary* to make further scientific progress towards the overarching goal of understanding whether life ever arose on Mars. If we use the phased exploration strategy advocated by the exobiologists in 1995 as a model, the Mariner 9, Viking and MGS orbiter data sets have/will provide a good deal of the global reconnaissance required in Phase 1, and the Viking and Pathfinder landers represent just the beginning of the in-situ analysis required in Phase 2. Simply put, from a scientific and technological standpoint, we are not at Phase 4 yet. We don't know where to go on Mars to get the samples we need to answer the life on Mars question, nor do we know how to design and build the vehicles and systems we need to accomplish a successful sample return mission, especially within the current resources of the Mars program. Putting sample return first is an extremely low-pay-off strategy that in most games, would signal naiveté, impatience, dishonesty or desperation.

A Post 2000 Strategy: The serious setbacks that have been experienced by the Mars program in recent months have provided us with a unique opportunity to reassess where we are going and what we are attempting to accomplish. I believe that the question of whether or not life ever arose on Mars provides a good unifying theme for the program. However, as has been pointed out in independent assessments of NASA's Mars exploration architecture by COMPLEX and elsewhere, that a definitive scientific answer to this question will require the accomplishment of a broad range of scientific investigations of all aspects of the planet – not just the analysis of a few grams of the first rock samples.

Since 1995, we have learned nothing which suggests that a phased exploration strategy as advocated by the Exobiologists should be substantially modified. The only outstanding issues relate to the pace of the program and its breadth. Clearly, the events of the last months have made it clear the "leapfrogging" is not going to work - not from a scientific standpoint, nor from a technological standpoint either. The notion that the next site we land at must necessarily be *the* site that we go to collect the first set of returned samples has got to be discouraged if we are ever going to explore the true diversity of the planet and its environmental history. Right now, we posses the technology and the resources to do a first-rate job of Martian global reconnaissance and in-situ exploration of a wide variety of sites.

There will always be scientists with laboratories who will advocate that NASA provide them with Mars samples for them to analyze. The fact is, however, that we don't yet have the technology to do this within acceptable levels of cost and risk. Those who are anxious to move the program forward toward sample return have more than enough to do in the areas of basic technological development, risk reduction and testing.

As we are able to attract more resources to the program, it is vital that we use them to in manner which maximizes program's excitement and further increases its scientific integrity. Key to this integrity is an increased emphasis on program breadth – to not just focus on the "life on Mars question", but to broaden the range of inquiry to encompass all relevant Mars science disciplines. While some may find this broad-based approach frustrating, one can point to a number of examples in the fields of earth and planetary sciences where the most important breakthroughs in real understanding have come from the comparison of data acquired from multiple disciplines. I believe that it is only through this approach that we will ultimately unlock the many secrets that the Red Planet has in store.

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After the Mars Polar Lander: Where to next? D. A. Paige[1] , W. V. Boynton[2], D. Crisp[3], E. DeJong[3], C. J. Hansen[3], A. M. Harri[4], H. U. Keller[5], L. A. Leshin[6], R. D. May[7], P. H. Smith[2], R. W. Zurek[3], [1]Dept. of Earth and Space Sciences, UCLA, Los Angeles, Ca 90095 dap@mvacs.ess.ucla.edu, [2]University of Arizona,. [3]Jet Propulsion Laboratory, [4]Finnish Meteorological Institute, [5]Max Planck Institute for Aeronomy, [6]Arizona State University, [7]Spectrasensors Inc.

Introduction: The recent loss of the Mars Polar Lander (MPL) mission represents a serious setback to Mars science and exploration. Targeted to land on the Martian south polar layered deposits at 76° S latitude and 195° W longitude, it would have been the first mission to study the geology, atmospheric environment and volatiles at a high-latitude landing site. Since the conception of the MPL mission, a Mars exploration strategy has emerged which focuses on Climate, Resources and Life, with the behavior and history of water as the unifying theme. A successful MPL mission would have made significant contributions towards these goals, particularly in understanding the distribution and behavior of near-surface water, and the nature and climate history of the south polar layered deposits. Unfortunately, due to concerns regarding the design of the MPL spacecraft, the rarity of direct trajectories that enable high-latitude landings, and funding, an exact reflight of MPL is not feasible within the present planning horizon. However, there remains significant interest in recapturing the scientific goals of the MPL mission. The following is a discussion of scientific and strategic issues relevant to planning the next polar lander mission, and beyond.

Volatiles and Atmospheric Measurements: MPL included the most sophisticated package of meteorology and volatile-sensing instruments ever flown. Its deployment at a high-latitude landing site during the late spring season would have provided the first opportunity to characterize global-scale weather patterns in the southern hemisphere, as well as measurements of the abundance of water ice and adsorbed water and carbon-dioxide in the soil, and water vapor in the overlying atmosphere. These would have been combined with orbital atmospheric sounding and general circulation models to provide a much better picture of the behavior and distribution of water on Mars. In-situ measurements like those intended by MPL are the only means of obtaining this type of information, and should definitely be repeated in future polar lander missions.

MGS Results: In 1995, when the concept for the MPL mission was originated, our understanding of Mars was based almost exclusively on then Viking and Mariner 9 datasets. Since that time, the Mars Global Surveyor (MGS) orbiter has provided significant new datasets which are revolutionizing our understanding of the planet. The MGS results in the north and south polar regions that have been published to date have been particularly exciting. MOLA topographic maps show that both polar caps have approximately 3 km of total relief; and have shapes that are consistent with those expected for large ice sheets. The MOLA data also suggest that both caps may have been significantly larger at some point in their past history [1]. The north polar cap lies in a regional topographic depression which may have once held an ancient ocean. The south polar deposits lie on a regional topographic high[2] , and show distinct evidence for glacial flow [1]. Both polar regions show evidence for the outflow of liquid water into surrounding depressions [2]. In the south, the flow of water can be traced into the Argyre basin, and then across the equator into the northern lowlands [3]. The high-resolution MOC images of the north and south polar caps show a diverse array of fresh surface textures on the residual caps and associated layered deposits which suggest that the polar regions are not presently being "mantled" by dust and ice as thought previously, but instead are being actively modified by processes that have as yet, been not defined [4,5]. In total, the MGS data suggest that the Martian polar regions we see today are the product of a complex climatological and hydrological history which may be intimately connected to the climatological and hydrological history of the planet as a whole.

Polar Landing Sites: MPL was the first Mars mission whose scientific strategy was driven by the desire to obtain detailed measurements at a pre-chosen landing site. Because of their extensive geographic extent, and the expected uniformity in their morphological characteristics, the south polar layered deposits represented an excellent target for the first polar lander mission. The north residual cap is another good example of a large, relatively homogeneous target. However, as we study the Martian polar regions in greater detail, it is becoming clear that to sample the true diversity of polar terrains, and to reconstruct the geologic and climatologic history they may contain, many more landings will eventually be required. In many cases, a precision landing with an error ellipse of less than 5 km would be required to enable detailed examination of specific features of great scientific interest, i.e. an exposure of layers or a suspected ancient outflow channel or esker deposit.

The Desirability of Landing Robustness and Mobility: One of the key new pieces of information that the MGS MOC images have provided, is that polar terrains that appear to be smooth and homogeneous at 1000m scales, are definitely not smooth and homogeneous on 10 m scales. Figure 1 shows examples of high-resolution textures in the north and south polar regions revealed by MOC.

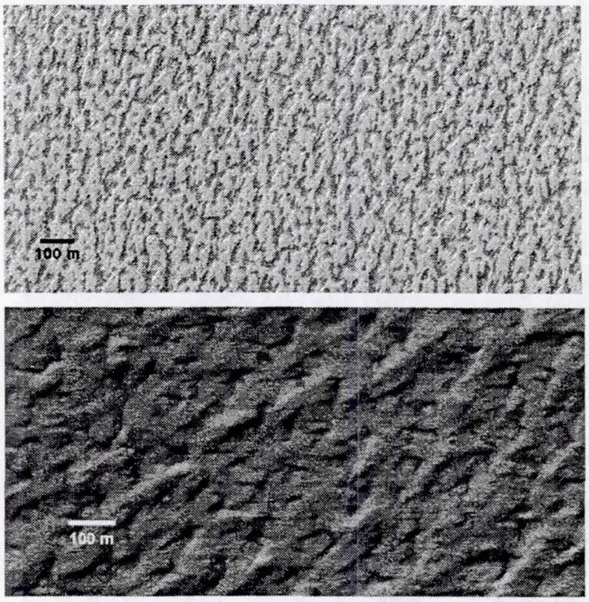

Figure 1. MGS MOC images of surface textures at the Martian north residual water ice cap (top), and south polar layered deposits (bottom). [6]

The implications of this new information are twofold. First, a robust landing system will be required to ensure safe landings on most polar terrains. Second, a mobile traverse of on the order of 200m should be sufficient to sample the fine-scale diversity of most polar terrains.

Instrumentation: The MPL MVACS payload developed a number of new experimental approaches and technologies that were successfully demonstrated in testing. The use of a dexterous, multi-jointed robotic arm to obtain surface and subsurface soil and ice samples within a wide workspace appears to be a very flexible approach that can be adapted to a wide range of future mission scenarios. Tests of the TEGA instrument demonstrated excellent sensitivity the presence of water ice and hydrated minerals in soil samples. The use of Tunable Diode Laser Spectrometers (TDL) to measure the concentration of water vapor and carbon dioxide gas in the Martian atmosphere, and in evolved gases from heated soil and ice samples is a powerful and robust approach. Improvements in TDL technology in future mission should enable detailed *in-situ* characterizations of the isotopic composition of Martian water and carbon-dioxide. The use of a focusable camera mounted on the robotic arm that can obtain close-up images of the surface and samples is also a very powerful technique that can be extended to true microscopic resolution on future payloads.

Future polar lander payloads should also include newly-developed instruments which could take advantage of the sample acquisition and analysis capabilities of the MVACS payload in a complimentary manner. For example, the addition of an organics detection experiment could significantly extend the search for near-surface organics begun by the Viking landers during the 1970's to environments that could have a greater potential for the preservation of organics.

Conclusions: While the near-term prospects for recovering the scientific objectives of the MPL mission are uncertain, it is clear that an integrated scientific strategy to study Mars' climate, resources and life must include detailed study of the polar regions at multiple landing sites. The MGS results indicate that both the north and south polar regions contain a number of sites of high-scientific interest, and that with foreseeable improvements in our capabilities for robust, precisely-targeted landers, these sites should be accessible to the next generation of Mars landers.

The scientific strategy advocated here is basically an extension of that originally employed for MPL. It starts with the selection of a specific landing site of high-scientific interest, followed by the design of a flexible integrated payload package that is capable of characterizing its environmental conditions, the abundance and behavior of its volatiles, and the fine-scale composition and geology of its deposits at and below the surface. While the return of samples from polar sites may result in significant additional science return, we are presently very far from a situation where sample return is *required* to make further scientific progress. Instead, we would argue that Mars science would be best served by a series of reliable *in-situ* missions which explore the diversity of the Martian surface environments, including those found at the north and south polar regions.

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ALADDIN: **EXPLORATION AND SAMPLE RETURN FROM THE MOONS OF MARS.** C. Pieters[1], A. Cheng[2], B. Clark[3], S. Murchie[2], J. Mustard[1], J. Papike[7], M. Zolensky[5] [1]Brown Univ., Providence, RI 02912; [2]Johns Hopkins Univ. Applied Physics Lab., Laurel, MD; [3]Lockeed Martin Astronautics, Denver, CO; [4]Univ. New Mexico, Albuquerque, NM, [5]NASA Johnson Space Center, Houston, TX

Mission Overview: Aladdin is a remote sensing and sample return mission focused on the two small moons of Mars, Phobos and Deimos. Understanding the moons of Mars will help us to understand the early history of Mars itself. Aladdin's primary objective is to acquire well-documented, representative samples from both moons and return them to Earth for detailed analyses. Samples arrive at Earth within three years of launch. Aladdin addresses several of NASA's highest priority science objectives: the origin and evolution of the Martian system (one of two silicate planets with satellites) and the composition and nature of small bodies (the building blocks of the solar system).

The Aladdin mission has been selected as a finalist in both the 1997 and 1999 Discovery competitions based on the high quality of science it would accomplish. The equivalent of Aladdin's Phase A development has been successfully completed, yielding a high degree of technical maturity.

Aladdin uses an innovative flyby sample acquisition method, described in detail in [1], which has been validated experimentally and does not require soft landing or anchoring. An initial phasing orbit at Mars reduces mission propulsion requirements, enabling Aladdin to use proven, low-risk chemical propulsion with good mass margin. This phasing orbit is followed by a five month elliptical mission during which there are redundant opportunities for acquisition of samples and characterization of their geologic context using remote sensing.

The Aladdin mission is a partnership between Brown University, the Johns Hopkins University Applied Physics Laboratory, Lockheed Martin Astronautics, and NASA Johnson Space Center.

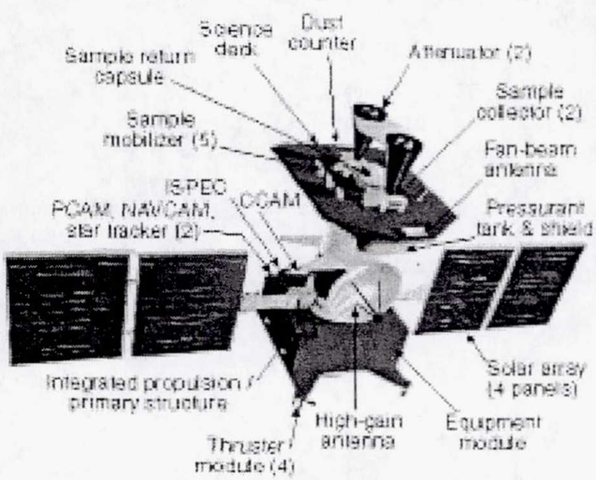

Fig. 1. The Aladdin spacecraft.

Science Background: How (and when) did Mars develop a system of satellites? How are the Martian satellites related to Mars itself? Are they indicative of common processes in the evolution of silicate planets or are they the products of special circumstances? On the one hand, Phobos and Deimos are postulated to be related to primitive outer solar system objects [2, 3]. The geology of each satellite is distinctive and complex [4, 5]. Both satellites have low densities and optical properties resembling primitive asteroids, and they may be the remnants of bodies that delivered organics, water, and other volatiles to the inner solar system. Such primitive bodies are not well represented in meteorite collections, but the proximity of Phobos and Deimos to Mars make them far more accessible with low-cost spacecraft. On the other hand, the two satellites exhibit spectra with a continuum that is similar to that of the Moon and Mercury [5]. This suggests their surface properties might be explained by a space-weathered silicate assemblage resembling bulk material of the terrestrial planets, having a common origin with or derived from Mars.

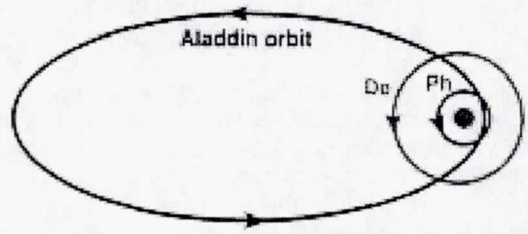

Fig 2. Aladdin's orbit at Mars has repeated encounters with Phobos and Deimos.

Resolving the origins and histories of the two satellites provides insight into early Martian history, but it requires detailed analysis of the mineralogy and chemistry of regolith samples that can only be performed using the advanced analytical capabilities of Earth-based facilities. These measurements will determine whether either moon co-accreted with Mars, is a captured more primitive asteroid or extinct comet, or is derived from Martian basin ejecta. With current analytical technology and expanding experience with IDPs, the amount of sample required to achieve these science objectives can be as small as 3 μg [6]. Aladdin is of course designed to collect far more than this requirement, orders of magnitude more material than the cumulative amount of IDPs analyzed to date. The availability of Aladdin samples in terrestrial laboratories would be a priceless resource for the planetary community, since it would enable questions not yet even conceived to be addressed using techniques not yet developed.

Sample Collection. Aladdin derives its name from its "flying carpet" sample collector, a flexible fiber maze trap. As described in [1] the spacecraft flies through a plume of debris released by small artificial impactors targeted at specific geologic formations on the satellites (two for Phobos, two for Deimos, plus a spare). Regolith particles from the surface are preserved during capture by the exposed carpet collector since both impact and collection velocities are relatively low (~1 km/s). Segments of the carpet are reeled into a sample return capsule (SRC) after each "launch and catch" event, retaining and protecting samples and allowing them to

be analyzed separately when returned to Earth. Onboard particle detectors confirm successful interception of each regolith sample. The Aladdin payload dedicated to sample collection includes 5 sample projectile launchers, sample collectors on a spooled carpet, the SRC, and the dust detector.

Remote Sensing: A coordinated series of remote sensing observations obtained before, during, and after sample acquisition place the sample sites in geologic context, and allow inference of global properties from detailed sample analyses. Aladdin's high resolution color imager (CCAM) and visible / near-infrared (0.45-3.6 μm) imaging spectrometer (ISPEC) are used to characterize the moons' surfaces and map geologic units and compositional variations. A specialized monochromatic camera records and locates the artificial impact plumes of regolith (PCAM). A panchromatic navigation camera (NAVCAM) provides optical navigation images for precision targeting.

Radio science experiments will provide significant improvements in the mass estimates, and hence derived density measurements, of both Phobos and Deimos. Knowledge of the densities of these two bodies is expected to be determined to within <10%.

In addition, Aladdin's ISPEC imaging spectrometer is capable of acquiring unique compositional measurements of the Martian surface, with no additional spacecraft or payload capability requirements. The spectral range and resolution of ISPEC are sufficient to discriminate features due to iron-bearing rock forming minerals (crystal field transitions), ferric oxides, and OH-bearing alteration minerals (overtones of vibrational absorptions). The wavelength range includes the regions where fundamental vibrational absorptions of carbonates occur near 3.5 μm. Coupled with these capabilities are a projected SNR that exceeds 200:1 in the visible, 800:1 in the SWIR, and 100:1 near 3 μm. ISPEC design thus provides an excellent opportunity for imaging spectrometer observations of Mars capable of mapping minerals indicative of aqueous environments. A 6000 km periapse orbit allows data to be acquired for Mars with a swath width of ~150 km at 600 m/pixel from equatorial regions to ±50° latitude. Extensive regions of high scientific priority will be mapped at high spatial resolution under high-sun lighting conditions. Aladdin data would provide exceptionally valuable information on Mars' mineralogy that is complementary to, but independent and distinctly different from, data obtained by the Mars Surveyor Program at longer wavelengths.

Table 1. Payload (Sample collection; Remote Sensing)

Instrument	Function
Sample Mobilizer	5 projectile launchers; create plumes of regolith sample from targeted areas on the satellites
Sample Collectors	5 independent carpet segments plus interconnecting leader; collects mobilized regolith.
SRC	Returns samples to Earth
Dust Counter	Detects >1 ng particles; confirms interception of sample
ISPEC Imaging Spectrometer	230 channels, 0.4 - 3.6 μm; characterizes and map mineralogy including Fe and hydrated species, organics
CCAM	characterize moons' geology
NAVCAM	High resolution panchromatic camera; optical navigation, morphology
PCAM	Wide-angle camera; images mobilized regolith plume

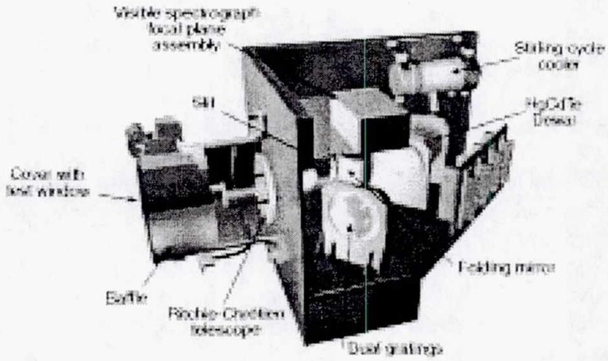

Fig 3. ISPEC, Aladdin's visible to near-infrared imaging spectrometer.

References: [1] Cheng et al. (2000) Concepts and Approaches for Mars Exploration, LPI. [2] Burns J. (1992) in *Mars* (Kieffer et al), 1283. [3] Bell J et al., (1993) in *Resoures of Near-Earth Space*, U AZ, 887. [4] Thomas P. et al. (1992) in *Mars* (Kieffer et al.) 1257. [5] Murchie S. and Erard S (1996) *Icarus*, 123, 63. [6] Zolensky et al. (1998) LPS29, 1716; Zolensky et al., (2000) *MAPS* 35, 9-29.

S36/25 2000110885 472730 Pg 2

ATOMIC FORCE MICROSCOPE FOR IMAGING AND SPECTROSCOPY W.T. Pike[1], M. H. Hecht[1], M. S. Anderson[1], T. Akiyama[2], S. Gautsch[2], N.F. de Rooij[2], U. Staufer[2], Ph. Niedermann[3], L. Howald[4], D. Müller[4], A. Tonin[5], H.-R. Hidber[5], [1]Jet Propulsion Laboratory, 4800 Oak Grove Dr. Pasadena, CA 91109-8099, USA, william.t.pike@jpl.nasa.gov [2]Institute of Microtechnology, Univ. of Neuchâtel, Jaquet-Droz 1, 2007 Neuchâtel, Switzerland. [3]CSEM, Jaquet-Droz 1, 2007 Neuchâtel, Switzerland, [4]Nanosurf AG, Austrasse 4, 4410 Liestal, Switzerland, [5]Insitute of Physics, Univ. of Basel, Klingelbergstr. 82 4056 Basel, Switzerland

Introduction: We have developed, built and tested an atomic force microscope (AFM) for extraterrestrial applications incorporating a micromachined tip array to allow for probe replacement. It is part of a microscopy station (Fig.1) originally intended for NASA's 2001 Mars lander to identify the size, distribution, and shape of Martian dust and soil particles. As well as imaging topographically down to nanometer resolution, this instrument can be used to reveal chemical information and perform infrared and Raman spectroscopy at unprecedented resolution.

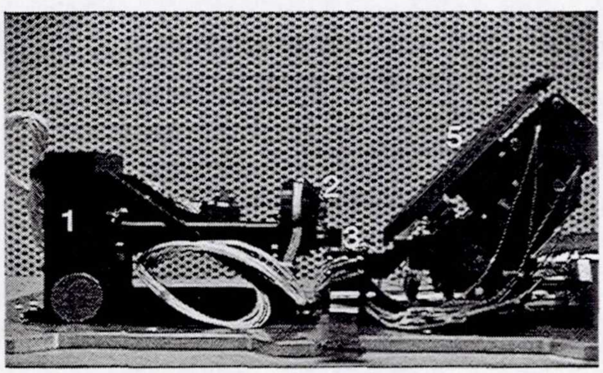

Fig. 1 *The microscopy station contains an optical microscope (1), LEDs for illumination (2), an AFM scanner (3) a controller electronics (4) and a sample wheel (5). The robot arm (6) puts soil samples onto different substrates which are then rotated and moved in front of the microscopes. Excess material falls off when turning the sample wheel from the 12 o'clock to the 6o'clock position.*

Instrument description: Atomic force microscopy has seen rapid growth in a remarkably short time [1-2]. A tip mounted on a thin cantilever is scanned over the substrate and the interaction between the tip and the substrate is detected by monitoring the deflection of the cantilever. In addition to topography,

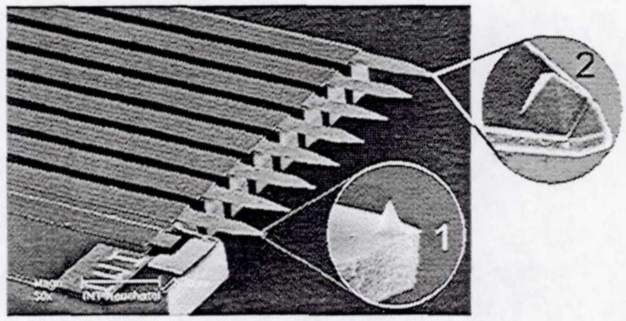

***Figure 2**. SEM picture of the microfabricated AFM chip with support beams etched by DRIE. The insets shows a silicon tip and a CVD molded diamond*

a variety of other signals are available from the AFM. Although most commonly used in terrestrial ambient conditions, the AFM can also operate in liquids and in vacuum over wide temperature ranges.

This AFM developed for planetary applications consists of a single printed-circuit board and a miniaturized scanner. The electronics incorporate radiation-hard components, latch-up protection, and a digital multivoting scheme on critical operation to minimize bit-flip errors. The scanner uses electromagnetic coils rather than the more conventional piezoelectric actuators for scanning in order to reduce volume, power, and voltage requirements. An array of tips has been fabricated using silicon micromachining (fig. 2). Each micromachined array features eight cantilevers for redundancy. Four are equipped with a monolithic silicon tip and four have a diamond tip. The diamond tips are fabricated by chemical vapor deposition into pyramidal silicon molds, and then transferred and affixed to the cantilevers. By mounting this array at an angle only one tip at a time is in the lowest, imaging position. Replacement of the tips and cantilevers, as they are worn down or fouled by material, is effected by cleaving off a complete cantilever and beam using a special tool on the sample wheel.

Cantilever deflection during scanning of the probe is measured by means of a piezoresistive Wheatstone bridge [3]. A reference resistor is incorporated on an ultra-short cantilever for compensating thermal drifts. The noise floor of the complete system, including contributions from electronics, stage and scanner, is about 2 nm.

Imaging: Preliminary AFM experiments using particles in the expected size range showed that

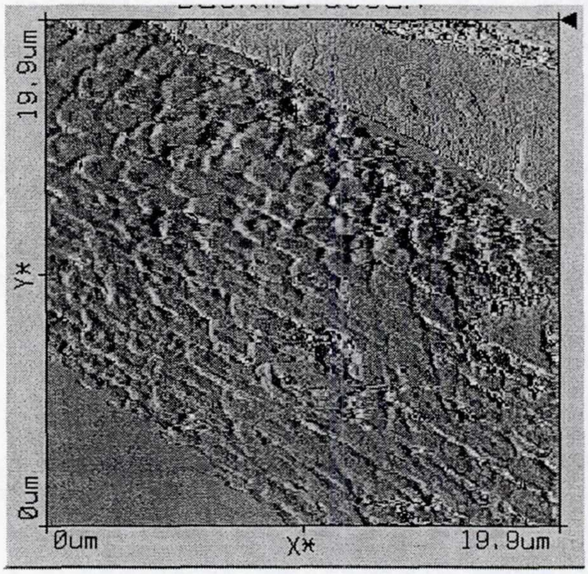

Fig.3: AFM image taken from a fragment of a diatom.

only dynamic mode can be used for imaging. In this mode, the chip is vibrated, exciting the cantilever at its resonance frequency and the tip experiences an interaction with the sample only at its most extended position. The lateral force on the particle and, hence, the chances of sweeping them across the substrate are thus reduced. In the case of the tip array, the excitation is sufficient to overcome the substantial crosstalk between the cantilevers which attenuates the energy injected into the required cantilever.

Figure 3 shows the image of a fragment of a diatom taken in dynamic mode. The image has been digitally differentiated to emphasize the hexagonal structure visible on the surface of the diatom. Phase-contrast imaging, which produces contrast dependent on the viscoelestic properties of the sample, is also possible with this instrument.

Spectroscopy: Using a separate AFM system we have demonstrated the capability of the AFM to produce local spectroscopic information. Both localized infra-red (IR) absorption spectroscopy [4] and Raman spectroscopy are accessible [5].

For IR spectroscopy the AFM deflection signal itself is used as an IR absorption sensor: the absobed IR energy from a chopped incident beam produces a thermal expansion of the sample which can be detected by the AFM tip.

Raman spectroscopy in general produces a weak signal. Using a metallized AFM tip to mediate the signal both enhances and localizes the Raman signal. Figure 4 shows schematically how an AFM tip concentrates the energy from a broad incident beam into Raman scattering. Figure 5 shows two Raman spectra with and without a metallized AFM tip. Both electromagnetic field enhancement and charge-transfer resonance are available mechanisms for the very large

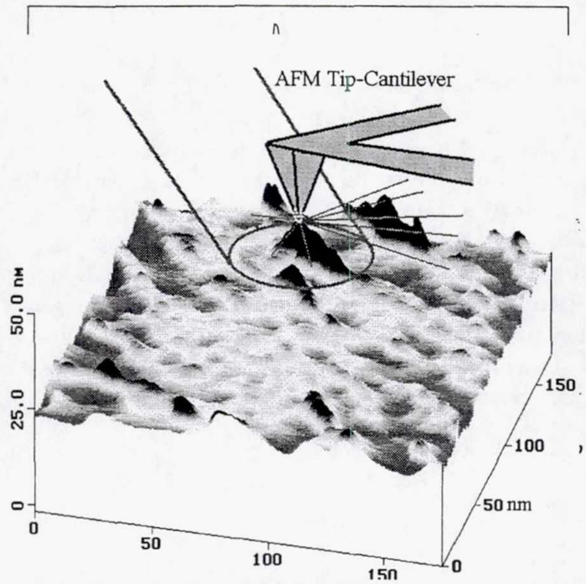

*Fig.4: Schematic of **an AFM-based Raman spectrometer***

gains observed in the Raman signal.

Conclusions: We have demonstrated the feasibility of an AFM for planetary applications. As well as imaging, several chemically imaging and spectroscopy modes are now available at unprecedented resolutions.

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537/91 ABS ONLY 20001108911 472731 pgs 2

ADAPTIVITY AND THE ARCHITECTUIRE FOR A NEW MARS EXPLORATION PROGRAM. J. D. Pinder[1] and M. I. Richardson[2], [1]RAND, 1700 Main Street, Santa Monica, CA 90407 (pinder@rand.org), [2]Division of Geological and Planetary Sciences, MC 150-21, Caltech, Pasadena, CA 91125 (mir@gps.caltech.edu).

Introduction: In spite of recent failures, the prospects for Mars exploration remain excellent. The motivation for such optimism is, ironically, rooted in cyclical constraints that are unique to this endeavor: steady annual funding of about $200 million; regular launch opportunities every 26 months; 4 to 6 years for the entire spacecraft development process; and 6 to 8 years for the science to unfold through instrument conception and design, and then converge through analysis and publication. These stable cycles create an important opportunity to employ an intelligent exploration strategy that is based on iteractive adaptation, using past triumphs and failures to shape future missions.

This stability, however, also poses a dangerous temptation to take the opposite approach: a static exploration strategy that is focused on a limited let of scientific objectives. Such an approach must, necessarily, rely on a single overarching "best guess" as to exactly which fixed sequence of missions is the most attractive, based on a host of assumptions about the cost, technical risk and potential scientific benefits of the options considered. This approach, however, is fundamentally flawed, even when implemented perfectly, because it does not allow lessons learned over time from both successes and failures to be incorporated into subsequent missions.

Description and Critique of Current Architecture: The Mars Surveyor Program became increasingly driven by a focused goal: that of searching for life or evidence for past life on Mars. In response to this mandate, a development program was implemented to accomplish the return of a sample. This endeavor would require development of a number of untested systems and ultimately require a rather complex chain of operations to accomplish. The development and implementation, driven by these very specific goals, became a facility program with missions defined for all opportunities out to some "distant" date. An assumption in this program was that capabilities could be developed sequentially, and that elements could be proven in a build up to sample return. Another significant assumption was that only sample return endeavors (and any small payload that could "ride along") were worth undertaking.

A major implementation problem for such architecture results from the inconsistency between launch opportunity cycles and spacecraft development cycles. One simply cannot undertake a true sequential (linear, dependent) program within these constraints: there isn't enough time to learn for failures / successes within the development / implementation cycle and retain robustness. A failure in a precursor mission can easily trap a successor mission in the ATLO (post-development, pre-launch) phase where great resources have already been expended on development, but only minor corrective measures can be undertaken. Such a circumstance occurred with the 2001 Lander following the demise of the Mars Polar Lander (MPL). For this reason, *we believe flying common spacecraft buses in subsequent missions to be a high-risk endeavor*. While this may be justified in some extreme circumstances, it can easily be avoided.

The program was forced into application of an architecture inconsistent with the nature of the opportunity due to the belief that only the search for life warranted missions, and that only by returning samples could that goal be met. This singular focus on sample return eliminated all other science, and hence the program's ability to survey the planet. By eliminating flexibility, this focus excluded any ability to follow up on the program's own discoveries or on changing scientific emphasis. More concerning to those interested in the exploration of Mars, this choice of focus set up an "Apolloian" goal that could be checked-off as completed when the first rocks came back from Mars. The danger of advertising sample return as the "be all and end all" of the Mars Surveyor Program is therefore to provide a false "mission accomplished" milestone which attracts cancellation before significant exploration of Mars could be undertaken.

Adaptable Strategies: The stable cycles unique to the current environment for Mars exploration create an opportunity to develop an adaptive architecture that explicitly feeds the technical and scientific outcomes of each mission into the planning process. This sort of flexibility in mission design and selection is especially appealing because it can accommodate the competing scientific objectives of Mars exploration, which often require fundamentally different types of missions. Picking a fixed mission sequence that is focused on one area of interest neglects the others, even if evidence gathered early on indicates that the sole objective is essentially impossible to achieve. By contrast, an adaptive approach that provides rules for selecting future missions using evidence from preceding missions, allows missions that contribute to different objectives to be staggered. In this way they occur in the intervening periods when the results of missions in other areas are being processed and their follow-on missions designed.

It has been shown in other areas of application that when new information is becoming available during the course of an extended endeavor, and multiple options exist for response to the evolving information base, the highest likelihood of success results from an adaptive strategy. In simple terms, while it is possible that notions of how to best accomplish an endeavor arrived at before the commencement will remain the best approach throughout, it is highly unlikely. This is simply a reflection of the fact that as the endeavor proceeds, things are learnt which improve understanding of the focus and implementation of the endeavor. We would be extremely lucky to have correctly guessed the relative importance of all elements which, at the outset, were poorly known. If it is assumed that we will evolve in understanding during the endeavor, then the best strategy becomes one of implementing the most efficient mechanisms for responding to evolving understanding. This requires a sufficiently broad definition of the scope of the endeavor at the outset, and development of mechanisms that foster continual reassessment of current understanding and adaptability in future implementation.

If it is decided that the goals of the exploration include understanding of Martian planetary and climatic evolution, including the central question of whether life evolved, as well as providing a thorough survey of Mars for potential future

exploration, then we strongly urge the implementation of an adaptive approach.

In essence, we are proposing that the Mars Exploration Program could better spend its energies on defining mechanisms which allow adaptability in mission development than in attempts to define a "long-term architecture" of defined missions, which will likely need to be entirely revised in a few years based on improved understanding of Mars and Mars exploration technologies. While the broad area of science and technology that needs to be accomplished by the program should be clearly defined from the outset, the best strategy of exploration is, in a manner of speaking, to have no strategy except to be as well prepared as possible for the next step ahead and to be fully aware of the available options. Louis Pasteur's quote "chance favors the prepared mind" could easily be adopted as "chance favors the prepared program of exploration".

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IMPACT CRATER HYDROTHERMAL NICHES FOR LIFE ON MARS: A QUESTION OF SCALE. K. O. Pope[1] D. E. Ames[2], S. W. Kieffer[3], and A. C. Ocampo[4], [1]Geo Eco Arc Research, 3220 N Street, NW, #132, Washington, DC 20007, kpope@primenet.com. [2]Geological Survey of Canada, 688-601 Booth St., Ottawa, Ontario, Canada. K1A 0E8. [3]S.W. Kieffer Science Consulting, Inc., P.O. Box 520 Bolton, Ontario, Canada L7E 5T4, [4]Code SD, NASA Headquarters, Washington DC 20546.

Introduction: A major focus in the search for fossil life on Mars is on ancient hydrothermal deposits [1, 2]. Nevertheless, remote sensing efforts have not found mineral assemblages characteristic of hydrothermal activity [3]. Future remote sensing work, including missions with higher spatial resolution, may detect localized hydrothermal deposits, but it is possible that dust mantles will prohibit detection from orbit and lander missions will be required. In anticipation of such missions, it is critical to develop a strategy for selecting potential hydrothermal sites on Mars. Such a strategy is being developed for volcanogenic hydrothermal systems [4], and a similar strategy is needed for impact hydrothermal systems.

Terrestrial Impact Craters: Hydrothermal deposits in terrestrial impact craters <100 km in diameter are limited to fracture and cavity fillings representing minor, short-lived hydrothermal circulation. In contrast, hydrothermal deposits in the ~200 km diameter Sudbury crater in Canada include an extensive basin-wide system and a system focussed along faults that fed a long-lived subaqueous vent complex (carbonate and chert) [5, 6]. The Sudbury vent system is similar to modern deep sea vent systems, known be excellent niches for thermophilic bacteria [7]. Preliminary studies of the ~200 km diameter Chicxulub crater indicate that it too may have had an extensive hydrothermal system [8]. We propose that large craters on Mars hold the most promise for preserving vestiges of extensive, long-lived hydrothermal systems and possibly life.

At Sudbury crater, hydrothermal circulation was driven by the 2.5-km-thick coherent melt sheet (melt mostly free of large unmelted clasts) within the crater. Smaller craters, with significantly thinner impact melt sheets, have minor hydrothermal activity, suggesting direct correlation between melt sheet thickness and the magnitude of the hydrothermal system. Furthermore, data from terrestrial craters indicate that there is an exponential relationship between crater size and coherent melt sheet thickness, and that there may be a size threshold for coherent melt sheet formation (Fig. 1). Most terrestrial craters <35 km in diameter have only mixtures of melt and unmelted clasts. To explain this phenomenon, Cintala and Grieve [9] have suggested that mixing of melt with unmelted clasts is a function of the ratio of melt volume/crater volume. Initially the melt is smeared on the bottom of the crater, and when the melt volume/crater volume is large, the mixed zone is a small fraction of the melt.

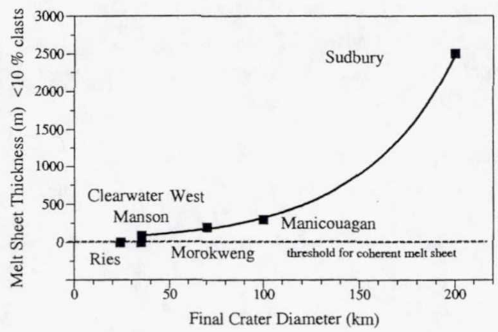

Figure 1. Melt sheet thickness and crater diameter.

When the melt volume/crater volume is small, erosional mixing of melt and clasts results in little to no clast-free melt. This is important because the incorporation of unmelted clasts in the melt can cool it quickly, greatly reducing the longevity of the hydrothermal system that develops.

Scaling for Mars. Before beginning the search for Martian analogues of the Sudbury Crater we must consider several aspects of crater formation that are gravity dependent, since Mars has about 1/3 the gravity of Earth. Due to this gravity difference, craters on Mars are about 1.24 times larger than craters on Earth (given impactors with the same mass and velocity). Another factor is projectile velocity. Typical velocities of asteroids and comets that impact Mars are ~ 19 km/s and 42 km/s, vs. ~25 km/s and 53 km/s on Earth [10]. Thus, for average craters with similar impact energies on Earth and Mars, Martian craters were formed by lower velocity (greater mass) projectiles. This is important because the mass of impact melt generated scales with V^2. When this relationship is coupled with the one above relating to larger craters on Mars, comparisons between crater size and melt can be made using the following equation [11]:

$$\frac{Mm}{Md} = 1.6 \times 10^{-7}(gDt)^{0.83}Vi^{0.33}$$

where Mm is the mass of impact melt, Md is the mass of rock displaced from the crater cavity, Dt is transient crater diameter (~0.5-0.6 final diameter), g is gravity, and Vi is the impact velocity.

We combined the empirical data on coherent melt thickness and gravity scaling to predict which craters on Mars are likely to have melt sheets capable of driving a long-lived hydrothermal system. The threshold final crater diameter for the formation of a coherent melt sheet on Earth is ~ 35 km, which corresponds with a Mm/Md = 0.11 (asteroid impact). Such a Mm/Md on Mars corresponds with a final crater diameter ~ 100 km (Fig. 1).

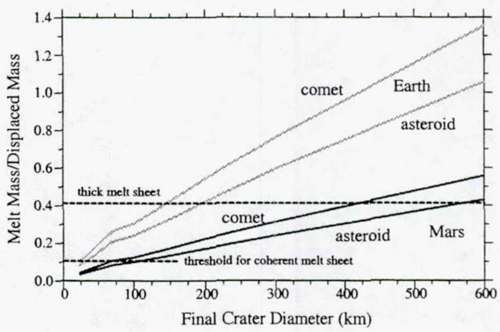

Figure 2. Scaling of Mm/Md for Earth and Mars.

Terrestrial craters with a thick coherent melt sheet such as Sudbury have a Mm/Md = 0.42, which on Mars corresponds with a final crater diameter of ~ 600 km (asteroid impact) or 440 km (comet impact).

Conclusions. We conclude that only very large craters on Mars have a high potential for developing long-lived hydrothermal systems. Martian craters < 100 km in diameter can probably be ruled out completely because they would produce melt mixed with a large number of clasts and therefore cool quickly. Craters < 200 km in diameter are tenuous, but may develop coherent melt sheets a few hundred meters thick (analogous to Manicouagan on Earth), which could drive a large, albeit short-lived, hydrothermal system. Martian craters capable of forming a Sudbury-like hydrothermal vent system fall in the 400 – 600 km size range. Such craters are rare on Mars (excluding ancient basins formed during the heavy bombardment period), which greatly limits the search. Candidates include Huygens (460 km), Schiaparelli (470 km) (Fig. 3), and Cassini (430 km).

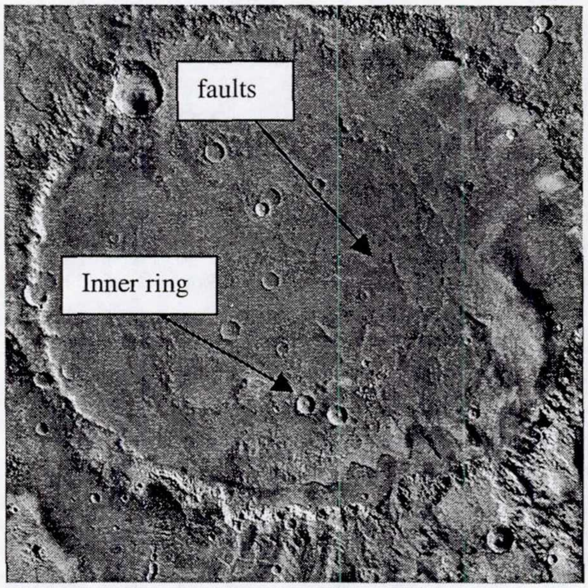

Figure 3. Schiaparelli crater, Mars (470 km diameter). By anaolgy to Sudbury, hydrothermal depoists may be found associated with faults inside the inner ring.

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539/91 2000110906 472733 P52

Sample Acquisition Systems for Sampling the Surface Down To 10 Meters Below the Surface for Mars Exploration. S. Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com), T. M. Myrick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, myrick@hbrobotics.com), S.P. Gorevan, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, gorevan@hbrobotics.com), K.Y. Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), S. Singh, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sase@hbrobotics.com), J. Ji , (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, chunlei@hbrobotics.com), C. Batting, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, cbatting@hbrobotics.com)

Introduction: Mars missions may benefit from sample acquisition systems under development that are capable of acquiring samples from the surface, from a few centimeters below the surface, from 1 meter below the surface and from 10 meters or more below the surface.

The SATM: The Sample Acquisition and Transfer Mechanism (SATM)[1] is a highly developed sampling tool that features interfaces with in-situ science instruments and sample return containers.

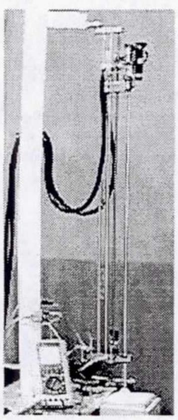

Figure 1: The 1 Meter Deep Drilling SATM Prototype

A prototype SATM has been developed and successfully tested at Honeybee Robotics to demonstrate the performance requirements necessary to meet the ST/4 Champollion mission goals., many of which could be applicable to a Mars sampling mission. The SATM has been designed to:

- acquire surface samples, samples at 20 centimeters below the surface and samples at 1 meter (or more) below the surface, without cross contamination. To accommodate the different sample volume requirements by each instrument, the SATM is also designed with a sample chamber that can be infinitely adjusted from 0.1 cc to 1.0 cc. A newer version of SATM is being planned for development in FY01 in collaboration with the JPL Exploration Technology program, where the sample volume will be increased to a maximum of 50.0 cc. This new SATM will also be capable of taking a core sample.
- transport and transfer samples to a microscope/IR spectrometer, chemical analysis ovens, and a sample return container. For the microscope, the SATM features a sapphire window through which the samples in the chamber can be presented for analysis.

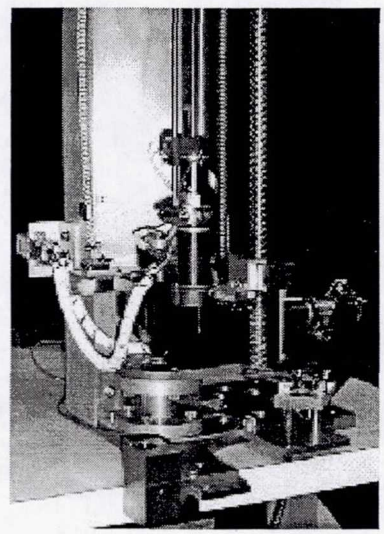

Figure 2: SATM Interface with OVEN

Deep Drilling Sampler: a Deep Drilling Sampler (DDS) for use on Mars has been initiated this year by Honeybee Robotics for the NASA PIDDP program. This system will be capable of acquiring and manipulating a stratigraphy maintained sample from 10 meters deep below the surface of Mars. The DDS technology will be a scalable, low mass (10-25 kg), small form factor (58cm x 37cm x 13 cm), deep drilling (5 m in the PIDDP implementation but easily scalable), core sampling robotic device. The DDS will be capable of supporting both in situ analyses of collected samples, as well as transferring of samples to sample return containers. The DDS samples can be taken from many depth levels and will always have its stratigraphy maintained.

Leveraging Mature Sample Acquisition Developments: The DDS is already quite developed as the basic drilling technology closely leverages the highly developed SATM.. Additionally the method of ac-

quiring the sample, with its stratigraphy maintained is closely related to the method first advanced by the Athena Mini-Corer, which is nearly flight ready. [1]

The DDS Sample Capture subsystem: The sample capture subsystem of the DDS is the mechanism capable of acquiring a stratigraphy maintained sample. During the development of the Mars Athena Mini-Corer, technology was developed that allowed core samples to be taken from rocks. The DDS will enhance this capability to enable the acquisition of short cores down to the 10-meter range. Furthermore the technology will be refined to allow a more complete sealing of the acquired sample so that unconsolidated samples may be acquired. Under the PIDDP effort, a breadboard will be developed to achieve these goals, by putting motors needed for actuation inside the lead drill string, and by enhancing the nested tube geometry to prevent loose grains from escaping the sample chamber. The motors inside this lead drill string provide a method of moving a center-drill/pushrod device used for drilling-sample ejection and for rotating the shear tube which shears the sampled core from the base rock and captures it inside the sample chamber. A key goal is to develop this technology into as small a form factor (small diameter drill string) as possible, while still maintaining high reliability and the strength needed to shear cores from strong rock.

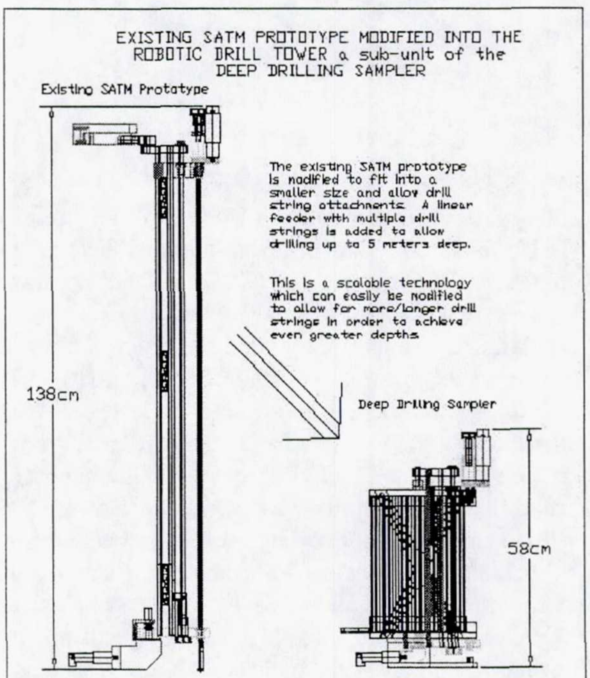

Figure 3: A copy of the existing Champollion/ST4 SATM prototype will be modified into a Robotic Drill Tower capable of accepting drill string segments.

To Reach 10 Meters Below the Surface: Deep drilling will be achieved by using multiple drill strings (segments) which can be autonomously attached to one another during drilling, and then detached during extraction. Instead of a tall drill tower with a single long drill string attached, a much smaller device will be created which will be able to use many smaller drill string segments. This segmented approach allows deep drilling to take place from a small, low mass device. . To enable this, a drill string feeder is being developed to present the individual drill strings to a robotic drill tower.

Miniature Samplers: Additional miniature sample acquisition systems have been developed by Honeybee Robotics under a NASA Phase I SBIR award.[2] They include:

- A miniature penetrator that is ballistically fired from a rover or lander. The miniature penetrator is tethered to a rover or a lander. Retraction of the penetrator activates a sampling mechanism that captures a sample at the furthest depth penetrated.
- A miniature inchworm sampling system that is deployed from a rover or a lander. This system employees an inchworm locomotion technique for subsurface travel.
- A telescoping sampling system is highly compact in the stowed condition but extends to the surface to acquire stratigraphy maintained cores.

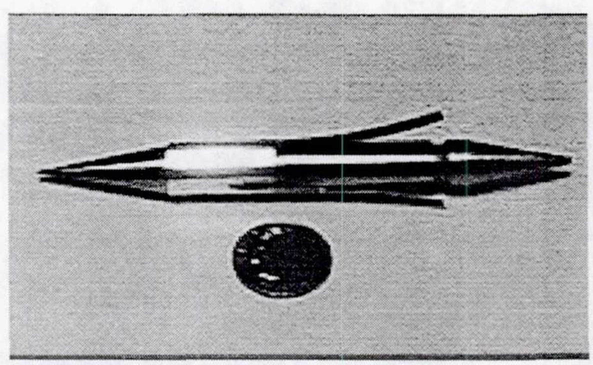

Figure 4: Miniature Penetrator Sample Acquisition System

References: [1]S.Gorevan,S.Rafeek, The SATM for Champollion, Advanced Developments in Space Robotics AIAA Tech. Forum, University of Wisconsin, August, 1996. S.Gorevan,T.Myrick, Shaheed Rafeek.

[2] Rover Mounted Sample Acquisition Systems, Proceedings of Interntl. Rover Conference, The Planetary Society, Santa Monica, CA, March 1997.

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Mars Balloon based Touch and Go Surface Sampler (TAGSS) – S. Rafeek, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, rafeek@hbrobotics.com), S. Stroescu, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sergiu@hbrobotics.com), K. Y. Kong, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, kykong@hbrobotics.com), S. Sadick, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, sadick@hbrobotics.com), P. W. Bartlett, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, bartlett@hbrobotics.com), K. R. Davis, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, krdavis@hbrobotics.com) and M. A. Ummy, (Honeybee Robotics, Inc., 204 Elizabeth Street, NY, NY 10012, ummy@hbrobotics.com).

Introduction

The Touch and Go Surface Sampler (TAGSS) is a new class of planetary body sample acquisition tool that can be used for Mars surface sampling. TAGSS in its basic configuration consists of a high speed sampling head attached to the end of a flexible shaft. The sampling head consists of counter rotating cutters that rotates at speeds of 3000 to 15000 RPM. The attractive feature of this "touch and go" type sampler is that there are no requirements for a lander.

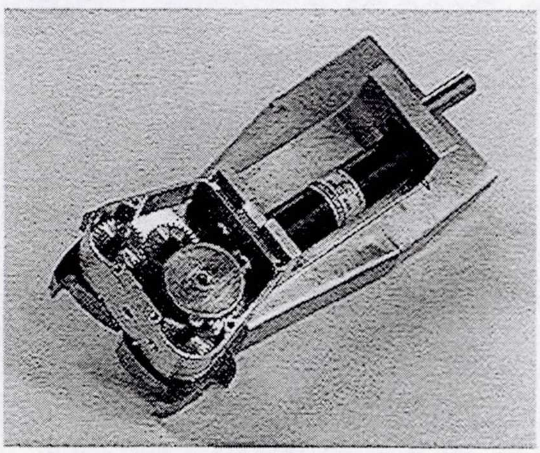

Figure 1: Phase I TAGSS Sample Head

Operation Sequence

Operationally, a hopping balloon craft with a TAGSS attached will descend to a selected surface site in a controlled manner with a predetermined surface relative speed. At a given height above the surface, the TAGSS will be deployed and energized. A leading contact sensor will give positive indication of sampling start time as the balloon continues its slow descent. The flex shaft (1.5 meters or longer) attached to the TAGSS will provide the required preload for sampling as the balloon continues its descent for an additional 1 to 2 seconds after the contact sensor have been triggered. The samples can either be collected and captured at the tool head or directly ejected through the Mars atmosphere towards onboard sample analyzer apertures located at the bottom of the balloon

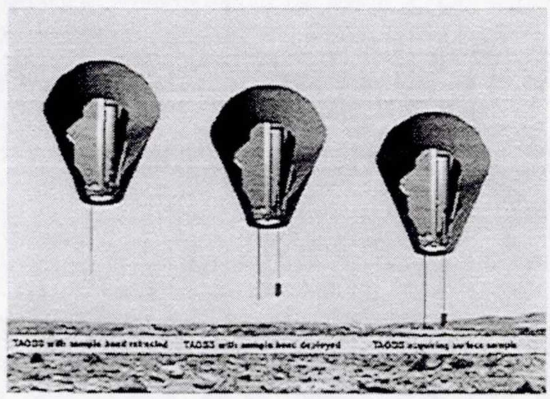

Figure 2: "Touch and Go" Sampling on Mars

payload/instrument bay. The high cutting-bit speed ensures that the ejected samples have enough momentum to reach the sample analyzers. In a controlled capture, the samples are contained in the head of the TAGSS and will be retracted into the payload/instrument bay of the balloon as the craft ascend back to a safe height.

Development Effort

A just completed NASA SBIR Phase I effort to test the validity of TAGSS as a surface sampler has yielded very positive results. Additional observation from the Phase I results show that TAGSS can be used for more than just surface sampling. The results gave strong evidence to suggest that TAGSS can be mechanically and functionally enhanced to penetrate the surface and obtain subsurface samples, possibly up to 1 meter in loose or low compressive strength material.

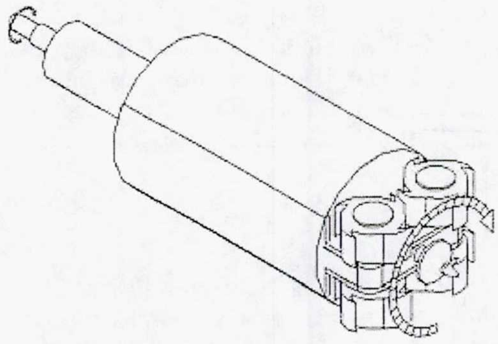

Figure 3: Proposed Phase II TAGSS Sample Head

Honeybee Robotics has submitted a Phase II SBIR proposal to secure funding to continue the development of TAGSS to add several mission critical elements to the sampling system, such as deeper penetration, automated deployment and controls and sample transfer capabilities.

A Mars balloon based mission can benefit from a TAGSS class sampler in a number of ways:

(1) In the "touch and go" mode, there are no requirements for a landing system. In past missions, the reliability of landing systems has resulted or contributed to failures resulting in the loss of entire payloads.

(2) TAGSS is better suited for unknown topography. The flexible shaft attached to the sampling head of TAGSS allows it to conform to the various sloped, hill, and depression contours of a Mars terrain.

(3) Samples can be obtained from multiple sites. A balloon based mission on Mars can "hop" from site to site taking samples for in-situ analysis or even for sample return.

(4) Reduced mission cost. With no requirements for a landing system or an orbiter, the cost of a TAGSS balloon mission to Mars will be greatly reduced.

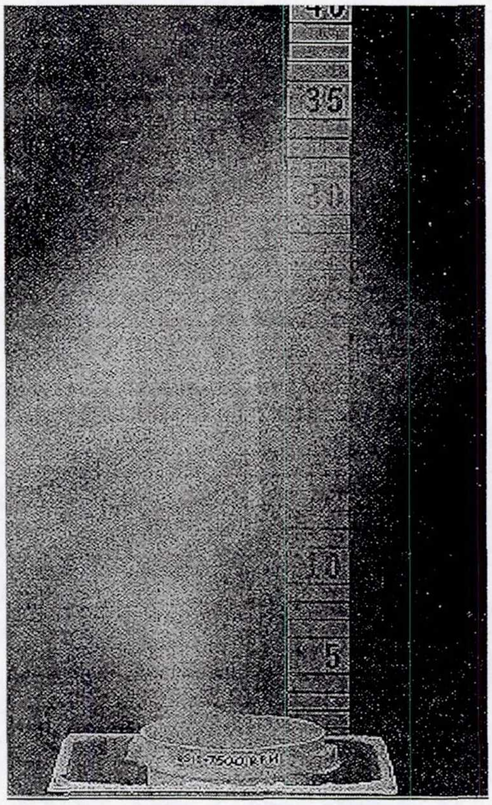

Figure 4: Sample Test Demonstration for Phase I – Surface Material Is Ejected with TAGSS Breadboard

References: NASA SBIR Phase I – Contract No. NAS2 – 00019, Dec 9, 1999.

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THE NEED FOR HIGH-RESOLUTION CRUSTAL MAGNETIC FIELD DATA ON MARS. C. A. Raymond[1], C. T. Russell[2], M. E. Purucker[3] and S. E. Smrekar[1], [1]Jet Propulsion Laboratory/Caltech (MS 183-501, 4800 Oak Grove Dr., Pasadena, CA 91109; craymond@jpl.nasa.gov; ssmrekar@jpl.nasa.gov), [2]IGPP/UCLA (Los Angeles, CA 90095; ctrussell@igpp.ucla.edu), [3]Raytheon ITSS at NASA/GSFC (Greenbelt, MD 20771; purucker@geomag.gsfc.nasa.gov)

Introduction: Magnetometer observations from the Mars Global Surveyor spacecraft (MAG/ER on MGS) have confirmed that Mars does not presently have an internally-generated dipole magnetic field, and have also revealed intense remanent magnetism in the Martian crust [1,2]. The remanent magnetic anomalies, most prevalent in the southern highlands region, are a record of the past history of the internal Mars dipole field. The MAG/ER data constitute a valuable data set for constraining the early thermal evolution of Mars and the history of the planetary magnetic field. However, the data lack the resolution needed to draw definite conclusions regarding the time history of the field. High-resolution magnetometer observations, obtained at low-altitude, are needed to complement and extend the MGS/ER data set and allow a definitive time history of the internal Mars dynamo to be constructed

Magnetic Fields and Life: The question of the chronology of the Martian magnetic field not only concerns the early thermal evolution and differentiation of the planet which are important topics by themselves, but it also is critical for understanding the stability of water in Mars' atmosphere and the radiation environment of the planet which both have significant impact on the emergence and sustainability of life on Mars. The shielding planetary magnetic field would have protected the atmosphere from erosion by the solar wind, and would have protected the surface from bombardment by cosmic rays.

The Need for Low-Altitude Magnetic Data: The MGS MAG/ER data are limited in spatial resolution to wavelengths above approximately 200 km at the periapsies. Resolution at higher altitudes is worse. At this resolution, it is predictable that of most of the features seen in the altitude- and spatially-binned data set that has been released [3] are actually low-pass filtered renderings of the true spatial anomaly pattern. It is difficult to assess the sources, and thus the causative processes that created the magnetized crust when the true scales are poorly understood. An example is the apparently non-magnetic region of the southern highlands surrounding the Hellas and Argyre basins, thought to have been demagnetized by the megaimpacts that created the basins[1]. This region may actually be magnetized at a very fine scale, which is not detectable at the spacecraft altitude, or it could be coherently magnetized (possess no magnetic contrasts). A sampling of the near-surface magnetic field is required to determine if the crust is indeed nonmagnetic before we can understand why it is so. The northern lowlands is another region that might possess a high frequency, low-amplitude anomaly pattern that defies detection at spacecraft altitudes. Until the true distribution of the remanent sources is known, the evaluation of the field history will be incomplete.

Measurement Requirements for Low-Altitude Magnetic Field Data: In order the characterize the higher order energy in the magnetic field power spectrum (the high-frequency spatial pattern), the following requirements should be met:

Altitude. A minimum altitude of 50 km is needed. The fields of near-surface sources drop off rapidly, and the altitude filter will smear very high frequency patterns. An altitude below 20 km should reveal nearly all the details of the pattern.

Coverage. At a minimum, profiles crossing several major magnetic contrasts (anomalies) as seen in the MGS data are needed. Ideally, the profiles would cross several 'stripes' in the Terrae Sirenum and Cimmeria regions [2], as well as cross the apparently nonmagnetic regions of the southern hemisphere, and over the boundary between the magnetized and nonmagnetized regions. Profiles crossing the dichotomy boundary would also be valuable, and over the northern lowlands and the Tharsis Rise. Only a few profiles would be sufficient to reveal the frequency distribution and thus increase the value of the MGS data considerably. A program of targeted observations spanning multiple missions would likely be needed to reach all the critical areas.

Magnetometer. An accuracy around 1 nT scalar should be met as a minimum requirement for fields up to several thousand nT. The dynamic range required is at least 50,000 nT, and ideally 100,000 nT. Vector measurements will help to identify ionospheric noise and details of the source dimensions, but most information will be derived from the scalar or radial component data.

Low-Altitude Mobile Platforms. There are several choices for obtaining the low-altitude data argued for. Orbiters, including highly elliptical orbits, cannot deliver the altitudes needed. Rovers and surface systems are too limited in mobility and too close to the surface to be effective. The best candidates are airplanes, air-

ships and balloon platforms. While an airplane would provide a targeting capability, the restricted range would make it a less effective means to obtain the data, unless a specific target was sought. Airships and balloons offer the greatest opportunity to collect significant data sets at altitudes below 10 km. Further work is needed to better define the relative advantages and disadvantages of each of these platforms relative to the scientific payoff.

References: [1] Acuna, M. H. and 12 authors (1999) *Science*, *284*, 790-793. [2] Connerney, J. E. C. and 9 authors (1999) *Science*, *284*, 794-798. [3] Purucker, M., D. Ravat, H. Frey, C. Voorhies, T. Sabaka, and M. Acuna (2000) Geophys. Res. Lett, in press.

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MARS ANALOG FIELD TRAINING OF ASTRONAUTS. James W. Rice, Jr., Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721-0092, USA; (jrice@lpl.arizona.edu).

Introduction

The latest high resolution MOC images reveal that Mars has had a very complex and rich geological history. This new and exciting discovery is perhaps best illustrated in the imagery which shows abundant layering in the walls of canyons, channels, craters, and scarps. Clearly, these types of sites can only be fully investigated and properly sampled by astronauts. Additionally, any thorough search for extinct and or extant life will have to be carried out by astronauts. This will involve great surface mobility, flexibility, deep subsurface drilling, and intelligence in the field; activities best accomplished by astronauts.

Some of the ideas expressed in this paper are from being a member of the joint NASA / LPI sponsored workshop on Mars Field Geology, Biology, and Paleontology held November, 1998 in Houston [1]. The purpose of this workshop was to formulate recommendations that would ultimately contribute to NASA policy regarding human exploration of Mars. Participants included world class field geologists, geochemists, biologists, paleontologists, Apollo astronauts who explored the Moon, the scientists who trained them, Space Shuttle and future Space Station astronauts, NASA/JSC EVA Office, and NASA mission planners.

The best geologist is the one who sees the most rocks

The Apollo astronauts received fairly extensive geological field training from numerous field geologists at the U.S. Geological Survey, various Universities, and NASA. These field exercises proved to be invaluable and contributed greatly to the achievement of all lunar surface science objectives (including intelligent sample acquisition and documentation). Moreover, these field based exercises were also useful in sharpening the skills and interaction of astronauts and the ground science teams.

Mars analog studies and geological field training exercises will be even more crucial in the manned exploration of Mars because of its rich and complex geological history (perhaps even biological history), unlike the Moon. This will present new and exciting challenges to the manned exploration of both the surface and subsurface of Mars. Astronauts will be able to carry out the proper field investigations for correct geological context of the landing site as well as the surrounding environs, conduct precision landings, maximize surface mobility, and also perform intelligent sample acquisition and interpretation.

When should the Mars analog field training program begin? It is not too early to begin preparing for the first Mars expedition and several reasons are mentioned below: (1) The art and skill of Field Geology can only be learned by being in the field. (2) Additionally, Field Geology is a cumulative science, meaning the more experience you get the better you get. (3) The links should be forged between the science, operations, and astronaut communities now because it will take time to achieve the collective experience level necessary for the proper interaction of these communities. This will prove invaluable in supporting and controlling a multi-year Mars expedition [2].

Field geology is a slow process. If what is found is not what the working hypothesis suggested should be there, then this new information needs to be factored in to modify the working hypothesis so that it will predict what will be found at the next stop. If these predictions come true, then confidence in that working hypothesis increases. Eventually, after all data is synthesized into the traverse, a 'final' geological evolution of the site will be proposed [3].

Field geology in a space suit is an even slower process. The field geologist typically will recon a site, take a few photographs, record his observations in a notebook, break some rocks open, inspect each with his hand lens to determine the texture, structures, and mineralogy of the sample so that he can give it the correct name, and collect those samples that seem diagnostic of the locality as well as any 'odd' samples. In a space suit most of these tasks will take longer or will be impossible to do (write notes, for example) so that these tasks will need to be accomplished by other means. Therefore, it is imperative that training begin sooner rather than later.

Astronauts attending the Workshop stated that experience shows it is best to select a crew weighted toward the primary scientific skills for the extensive surface mission, and cross-train them to accomplish the spacecraft systems, operations, and maintenance functions [2]. Apollo and Space Shuttle experience indicates that scientists can successfully acquire the essential mission operations skills

in just a few years of spaceflight training, while the reverse process of training pilots and technicians for a primary science role will not work on a similar time scale. Geologist and Apollo 17 astronaut Jack Schmitt's estimate is that during Apollo, the scientists had acquired 75% of the operations skills of the pilots in the program, while the latter had attained 25% of the field geology skills typical of active field geologists. Our consensus was that successful cross-training can be accomplished over a period of about 10 years. That's about the time scale for development of expert operations skills via actual spaceflight experience on shuttle and station, experience that is a likely prerequisite for Mars mission candidates [2].

The author has been a geological field team member on numerous national and multinational expeditions of short and long duration (up to 6 months) to Antarctica, Devon Island in the Canadian High Arctic, Iceland, Paleolake Bonneville in Utah, Channeled Scabland in Washington, and numerous other sites in the American southwest and Mexico. It will be useful to train the crews in both modern and ancient processes / environments. The merit of studying an active flood or volcano provides valuable insight into both processes and landform development. The following sites are excellent Mars analogs and will be discussed in more detail below. This list is not meant to be complete and final but rather a starting point of where to begin the process of Mars analog field training of astronauts in the near future.

Antarctica: The ice free desert regions of Antarctica are no doubt the best Mars analogs in terms of mean annual temperature, aridity, winds, and remoteness. These regions also contain relevant Martian analogs such as ancient lake deposits, deltas, sand dunes, cinder cones, and periglacial processes and landforms. Glacial landforms have been postulated for Mars and these regions obviously contain glacial landforms. The field investigation of Antarctic microbial life habitats (i.e., endoliths, crypto-endoliths, chasma-liths) would also provide useful training for Mars missions.

Iceland: Provides active and ancient volcano – ice interactions, hydrothermal sites, jökulhlaups (active and ancient catastrophic floods), periglacial, and glacial processes and landforms.

Devon Island: A 20 mya (20 km diam) impact crater in a periglacial environment is the key landform. This crater also once contained a lake.

Channeled Scabland: Largest paleoflood in the world. Ideal site for studying large scale catastrophic flood features.

Paleolake Bonneville: One of the largest paleolakes in the world with excellent preservation of shoreline morphology and lake sediments, and also contains evidence of volcanic eruption (Pavant Butte) into lake.

Meteor Crater: Impact crater used in training of Apollo astronauts.

Grand Canyon: Small scale analog to Valles Marineris, useful for stratigraphic studies.

Death Valley: Numerous landforms (volcanoes, playas, arroyos, debris flows, dunes, alluvial fans, lake sediments, spring deposits, evaporite deposits, fault scarps).

Yellowstone: Hydrothermal processes.

Atacama Desert: Extremely high altitude arid desert with playas, channels, debris flows, small impact crater.

Hawaii: Active volcanoes.

The establishment of an ongoing program of scientific field exercises geared toward Mars surface exploration will allow astronauts to gain valuable experience in managing a field research program, practice on site decision making, cope with changing research strategies, and to develop the cross training necessary for a successful expedition [2]. Astronauts participating in Mars analog field work should be equipped with the same tools and equipment that they will use on Mars in order to practice techniques and to allow the crew members to become familiar with the capabilities and limits of their equipment. These analog field expeditions will also blend real scientific field work by the astronauts with a ground support team. These activities should also have built in transmission delays and will foster the required interaction between the field team and ground support teams. It should be noted that because of time delays the astronauts will mostly be "on their own". Finally, these analog field expeditions should be geared toward accomplishing real scientific work not merely observation.

References: [1] Budden, N.A., 1999, Mars Field Geology, Biology, and Paleontology Workshop: Summary and Recommendations, LPI Contrib. No. 968, 80p. [2] Jones, T., et al., 1999, Crew skills and training, in Mars Field Geology, Biology, and Paleontology Workshop: Summary and Recommendations, N.A. Budden ed., LPI Contrib. No. 968, p. 25-30. [3] Muehlberger, W.R., et al., 1999, Approach to Mars field geology, in Mars Field Geology, Biology, and Paleontology Workshop: Summary and Recommendations, N.A. Budden ed., LPI Contrib. No. 968, p. 5-13.

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THE "WHY" AND THE "WHAT": THE SCIENCE FOCUS OF THE MARS EXPLORATION PROGRAM.

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Introduction: The high-level scientific goals and themes of the Mars Exploration Program place important requirements on the nature and architecture of the program. Choices at this level impact not only the particular sequence of missions to be flown, but also the program's saleability, the extent to which the planetary science community is engaged in the program, and the ultimate value of the program both to our understanding of Mars and as a survey tool for deciding whether humans should venture there. We briefly review the history of scientific interest in Mars, through to the inception of the Mars Surveyor Program (MSP). While the MSP began as a relatively broad-based investigation of Mars, the excitement surrounding the "discovery" of life in the Martian meteorite ALH 84001 redirected the program onto a pathway almost singularly focused on searching for fossil (or even extent) life in returned samples. We support the notion that the question of life is the single most important theme in Martian exploration. However, we argue that the approach that has evolved in the MSP - and would govern missions to be flown beyond 2001 - is overly focused. This threatens the utility of the program as a means of understanding the cause and context of life's absence or presence. The rush to a yes-or-no answer on life has also placed technical strain on the program, will ultimately disenfranchise a significant fraction of the scientific community, and will seriously limit the ability of the program to "survey" the planet for future exploration.

Interest in Mars Through to Viking: Historically, interest in Mars has centered on perceived Earth-like conditions and the potential for life. This interest can be traced back at least as far the 1698 publication of Kosmotheros, in which the Dutch astronomer Christian Huygens speculated about life on Mars and other worlds. Later astronomers discovered polar caps, a length of day and axial tilt like those of the Earth, a thin atmosphere, clouds, and variations in surface features resembling seasonal changes. Primitive Martian plant life was still considered possible until 1964 when the Mariner spacecraft began reaching the planet and revealed it to be a desolate, dry, and intensely cold world. Mars presented a very "lunar" visage to the earlier Mariners, but excitement about life, albeit microscopic, resurfaced after Mariner 9 provided ample evidence for liquid water at some point in Martian history. However, stock in Mars as a habitable planet fell to a new low in 1976 when twin Viking landers specially designed to look for life were sent to two widely separated locations on Mars Instead of life, they found a soil so highly oxidizing that it is lethal to all life as we know it and would likely obliterate evidence of that life.

The Mars Surveyor Program. Despite the disappointments, the Mariner and Viking spacecraft made fantastic discoveries, including extinct volcanoes, valleys and channels apparently carved by running water, and evidence for ground ice and a thicker early atmosphere. A new paradigm arose of Mars as a planet with a warmer, wetter, and more active past - perhaps similar to the Earth when it hosted primitive life, and motivated ideas of searching for microfossils or hardy subsurface life like that found in "extreme" environments on Earth. The question of life was now set firmly within the context of planetary evolution and climate evolution. The discoveries provided an image of a world far more Earth-like than any other in the solar system, with an active climate system which likely varied significantly through the planet's history. Successive missions were developed to examine the planet and its environment in greater detail. The establishment of the Mars Surveyor Program (MSP) followed the failure of the Mars Observer (MO) and the cancellation of the Mars Environmental Survey missions, but initially retained their inclusive goals. However, three years after the advent of MSP, the claim of fossil life in the Martian meteorite ALH 84001 generated tremendous excitement and controversy and the search for life once again shifted to dominate Mars exploration. This altered focus provided impetuous for ambitious plans to return samples from the surface of Mars in 2005 in hopes of finding life in them. The decision to return samples so soon influenced preceding missions: the primary payload for the 2001 lander was chosen to be a rover that would serve in later missions as a vehicle to find and retrieve samples. On the 2001 orbiter, the reflight of the MO gamma ray spectrometer was to be accompanied by an instrument selected primarily in terms of sample-return landing-site selection. The effort required to develop a sample return vehicle demanded that orbiter science be eliminated after the 2001 mission. Further, instruments on landers were either to address sample return-related issues, or make measurements deemed essential for future human missions to Mars. The exploration program

would thereafter consist of sample return missions into the second decade of the 21st century.

The Search for Life in Context. The question of life on Mars is a profound one, but a single-minded focus on a yes or no answer is an intellectually impoverishing reduction of the study of planetary habitability. The search for life is but one of a suite of many questions which provide both cause and context. Over the course of three decades of exploration, we have come to appreciate Mars as a complex world shaped by volcanism, wind, ice, and, at least occasionally, the flow of liquid water. It is a planet whose evolutionary path has diverged from the Earth's for reasons that are poorly understood but are profound for life. That the non-science public appreciates this is evidenced by the enormous interest in the pictures from the Mars pathfinder that revealed a landscape far more lifeless than any place on Earth.

Using Sample Return to Look for Life: Sample return as a scientific experiment is poorly posed. There is a straightforward reason for this. At it's heart is the testable hypothesis that life at one time was sufficiently abundant that it's signature may now be found in rocks on the Martian surface. This is a non-falsifiable hypothesis in that while it may be proven by finding a single rock with evidence for life in it, it can only be disproved by examining every single rock on the Martian surface. What makes the problem even more serious is that unambiguous "biomarkers" have yet to be identified, while efforts to clearly prove or disprove purported evidence for life in one of the Martian rocks we already have in our laboratories has proven frustratingly unsuccessful and contentious. There is no *a priori* reason to expect greater clarity in returned samples: our knowledge of how to detect life within its broadest definition is still far from mature. We cannot predict how we will detect signs of life on Mars any better than we can predict if we will detect it.

Evolving Science Questions: Our picture of Mars continues to evolve as a consequence of the successes of the Mars Surveyor Program: New data returned by the Mars Global Surveyor (MGS) has not shown the carbonates or diverse minerals, or other evidence expected if there were an early, warm, wet climate. On the other hand, MGS data have uncovered new enigmas, such as the magnetic lineation of the southern highlands, which demand further investigation.

Exploration of a planet within a sustained and aggressive program is novel to NASA's robotic exploration endeavor. Typically, there has been substantial cycle time between missions to allow results to be digested and new directions discerned. The lack of cycle time within the Mars Surveyor Program undermines long-range planning which seeks to lay out detailed mission scenarios, especially if that program becomes overly focused on a single question. One of lessons of exploration is that our understanding of what is important will continue to evolve as we obtain more data and have additional time to analyze and model them. Neither the oxidizing soils nor the magnetic anomalies of Mars were predicted before the arrival of spacecraft and instruments to detect them. Both are important clues to Mars' past environment. Should the MSP as planned in late 1999, the return of a small amount of sample from the near surface at a restricted choice of landing sites will provide data for important questions about Mars. The existence of past or present life will probably not be among them - this makes use of sample return as a vehicle to search for life a high risk, long-odds endeavor. If sample return technologies are developed, a better posed and guaranteed scientific experiment would be to absolutely date the early geological provinces. In any case, evidence to date suggests that sample return simply cannot be undertaken within the bounds of the program without eliminating all other science. We seriously doubt whether this is scientifically warranted.

A Broad Scientific Agenda: The successes of the Mariner, Viking, and Mars Global Surveyor missions have revealed a complex and exciting world in our planetary neighbor. Many of the questions we have about Mars reflect concerns we have about our own world: How did the planet evolve and what determined the pathways? How does the climate system operate and what feedback systems operate to stabilize or destabilize the climate? How do geologic and tectonic processes operate and what determines their style, how does the planet interact with the solar wind and what does this imply for atmospheric evolution? What is the history of life and what determined this history?

The Mars Surveyor Program represents an open-ended commitment to explore our neighboring planet. This commitment results from the fascinating similarities of this world to our own, and the fact that if humans venture away from the Earth/Moon system, Mars will be the destination. In view of this commitment and the broad range of scientific questions, we see no valid reason to overstrain the program by rushing into sample return. As explorers we seek the thrill of taking each new step, not winning an Apollonian race. Mars is not going away: As long as the human species endures, it will continue to beckon new generations of explorers.

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A TWO-STREAM MODEL FOR THE MARS EXPLORATION PROGRAM. M. I. Richardson[1], I. J. McEwan[2], and A. R. Vasavada [1]Division of Geological and Planetary Sciences, MC 150-21, Caltech, Pasadena, CA 91125 (mir@gps.caltech.edu), [2]Dept. of Earth and Space Sciences, UCLA, Los Angeles, CA 90095.

Introduction: The Mars Exploration Program represents an unprecedented opportunity to study and explore a planet and an environment beyond our own. While this opportunity represents the most important development in planetary exploration since the initial robotic survey of the solar system, it presents organizational and architectural challenges that have simply not been faced in the NASA robotic exploration endeavor to date. These challenges, of flying frequent, probably interrelated missions to Mars within a moderate, flat fiscal environment, were responded to in the late 1990's by the Mars Surveyor Program. The architecture that evolved within this program became singularly motivated by the search for life and singularly focused upon a sample return mission (to be executed over many opportunities.) The strategy behind this architecture sought to provide a clear rationale, develop common engineering systems, and centrally execute an ambitious technical program. We argue that the singular focus on the search for life and on the highly ambitious sample return strategy - while well motivated in terms of developing program coherence - forced the program into a non-optimal architecture and caused it to overreach its means. We will argue that the focused and centralized nature of the program seriously limited its ability to respond to failures or successes; overly strained the program by coupling broad constituencies with a highly ambitious technical approach, and ultimately stifled competition, creativity, and responsiveness as the Announcement of Opportunity (AO) system was abandoned in favor of facility development.

Proposal: In this abstract, we propose a new architecture for the program which will reinfuse community creativity while reducing programmatic risk resulting from individual mission failures. A major precept of this proposal is that the science goals of the program must return to those under which the Mars Surveyor Program was founded: a broad emphasis on planetary evolution, climate evolution and environment, preparatory science to support further exploration, each placed along side the search for life. Further, it must be realized that the while program is primarily justified as a scientific endeavor, it must also serve as its own technology and infrastructure development program. In order that the program doesn't become limited by inability to develop necessary technologies (by over-focusing on science) or worse, become fixed on developing technology alone (while neglecting science), appropriate balances need to be built into the program at an organizational level. Finally, the on-going nature of the program suggests that new discoveries and developments will occur during the course of the program, and that developing *a priori* a rigid sequence of missions may be the wrong way of thinking about program "architecture" entirely.

In view of these facts, we propose that the program be broken into two parallel "streams" or "branches". The first stream would be solely focused on the scientific exploration of Mars. This program would be organized in a similar manner to that of the Discovery program: integrated payload/spacecraft systems would be selected through an AO system, and would be led by a Project Manager / Principal Investigator team. The AO should be nearly the same for every opportunity: the proposal should be allowed to address any scientific issue (including those associated with human exploration) within the purview of the program, and the only constraints should be time and cost. The second stream would concentrate on the development and in-flight testing of technologies to be infused at a later date into the science stream. Particular missions flown in this stream would be selected by a mix of AO response and program commission. The direction of the technology stream should be determined by the perceived need for particular capabilities, as defined by the science and/or human exploration communities.

It is extremely important that large, distinct endeavors that do not fall within the scope, schedule, or cost constraints of either of these streams (such as Sample Return or a Mars orbital communications/navigations network) should not be "shoehorned" into them. Program stability dictates that the twin streams be considered the program core and that there funding be held fixed. Additional endeavors should be considered as separate line-items whose merit may be independently assessed.

The "Mars Discovery" Program: The relationship between science and technology within the late 1999's Mars Surveyor Program ultimately led to extremely disappointing results. The "science" pressure for sample return placed a highly challenging goal before the engineers, while the overreaching demands of developing the sample return technology eventually lead to an increasingly impoverished scientific program. The problems were exacerbated as scientists and engineers competed for the same pot of money. It was the implosion of the post-1998 program (sample return and its precursors), rather than the failures of the 1998 missions, which posed the greatest risk to the program as a whole.

Worthwhile scientific missions are carefully crafted scientific experiments: the gulf between doing the experiment right or simply doing something can be as yawning as the gulf between doing it right and not doing it at all. Compromise must be carefully

weighed by the experimenter. For this reason, the PI-led integrated payload represents the pinnacle of scientific space exploration. But most importantly, it argues for separating concerns of technology development from scientific experiment. In the extreme case of the late 1990's Mars Surveyor Program, science was largely abandoned due to the imperative of developing the sample return technology. If the Mars Exploration Program is to be justified as an effort to explore and learn about Mars, there must be a continuing core element of the program that does that.

Given that we are interested in exploring Mars and that the program will continue to improve and shape our questions about the planet, an open and adaptable program is preferable. This suggests that a clear but broad statement of scientific goals should be established which will serve as the compass for the scientific program. Such goals can be based on COMPLEX/MEPAG reports, or on the results of a special program scientific panel (preferably an open one). In any case, we believe that the goals will ultimately be defined in terms of planetary evolution, climate evolution, environment, resources, and life. These program goals should be held as a constant target for the creativity of the scientific and engineering communities. As the ability to accomplish a scientific experiment is intimately related to the means by which the experiment is undertaken, we strongly suggest the Discovery mission approach of selecting an integrated mission model. Imposing spacecraft systems, or worse, setting up payload definition teams to define what goals can be addressed or even what instruments can be flown, greatly diminishes scientific freedom and hence stifles creativity within the program. Allowing a single, scientifically competent, AO-selected team to assess trades will guarantee the best science return and will eliminate the unnecessary interfaces that harmed the 1998 missions.

What is an "Architecture?" Central to the "Mars Discovery" vision for the science program is a necessary change in thinking about what an "architecture" is. This shift in thinking requires that we no longer attempt to plan out a defined sequence of missions into the foreseeable future (which is always shorter than we expect it is!), but develop those programmatic mechanisms which will allow the program to best adapt to the changing questions we have about Mars. Fostering opportunity for creativity within the program would further suggest this transition in thinking. Effort needs to be expended in designing mechanisms which allow numerous instrument concepts, spacecraft concepts, and mission concepts to be clarified that can openly compete for development funds and launch opportunities. Effort also needs to be expended on prudent designation of common elements, and the best way to make these elements available to the mission teams. In this sense, the program organization may become centered around two endeavors. The first would be providing a mission "incubator" environment, in which potential PI's or instrument/spacecraft engineers can easily find resources to better place them to compete for launch opportunities through the AO system - and better place NASA to launch the highest quality scientific missions. Such resources could include access to facilities such as mission planning tools and personnel, the provision of small "seed" grants for instrument or mission concepts, access to technical advise, and development of an instrument "registry" which might allow integrated payloads to be put together more readily and openly.

The second should be focused on how to develop the broad targets for the missions and emplacing mechanisms to determine which missions are selected for development and flight. We have already discussed goal definition. For selection, we advocate separate scientific and technical panels to assess the scientific value and technical feasibility of the missions. Final selection should be left to the program leadership, where scientific, technical, and political interests may be weighed.

Engineering Program: The engineering stream of the program would be implemented to eliminate "science pressure" from the task of developing important hardware. Such "science pressure" arguably harmed the development of long-range rovers and sample return technologies within the Mars Surveyor Program. The goals of the Engineering Program would be developed from perceived needs for exploration capabilities, such as robust landing systems, small network emplacement technology, balloon systems, *etc*. The Program could also test technologies and undertake some of the experiments necessary or likely useful for human exploration. These may include *in situ* resource processing, mechanical system suitability for prolonged exposure to the Mars environment, *etc*. The selection process could be facility driven, but we again recommend the advantages of the AO system.

Advantages of the Twin Stream Model: The twin stream model clearly separates the goals of technology development and scientific exploration in such a way that neither are neglected. Alternating launch opportunities within this structure increases program robustness, as common spacecraft system should not, in general, be scheduled for consecutive opportunities. It greatly increases the opportunity for scientific and technical progress by allowing the program to adapt to new information, and by reopening the realm of what is possible within the program. By allowing a variety of activities, it should provide an exciting era of vicarious exploration to engage the public well into the future.

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The Athena Alpha Proton X-Ray Spectrometer (APXS). R. Rieder[1], J. Brückner[1], G. Klingelhöfer[2], R. Gellert[2], G. Dreibus[1], G. Lugmair[1], H. Wänke[1], and the Athena Science Team, [1]Max-Planck-Institut f. Chemie, Postfach 3060, D-55020 Mainz, Germany (rieder@mpch-mainz.mpg.de), [2]Institut f. Anorganische u. Analytische Chemie, Joh. Gutenberg-Universität, Staudinger Weg 9, D-55099 Mainz, Germany (klingel@mail.uni-mainz.de).

Introduction: During the Mars Pathfinder Mission in the summer of 1997, martian rocks were analyzed for the first time by a small instrument: the Alpha Proton X-Ray Spectrometer (APXS). This instrument was carried by the Sojourner rover to a number of soil and rock targets to obtain their elemental composition. The performance of the APXS permitted characterization of the landing site in an unprecedented way. New insights into soils and rocks on Mars were derived that could not have been obtained otherwise [1].

An advanced APXS instrument has been designed for the comet nucleus lander on the European Rosetta mission. The flight version is being completed presently, and a copy of this instrument will be used as part of the Athena rover payload for in-situ exploration of Mars.

Instrument Description: The new APXS is based on the successful APXS used for Pathfinder [2]. The new APXS sensor head has two modes to determine the elemental composition of a sample: Rutherford backscattering (alpha mode), and alpha and x-ray induced x-ray emission (x-ray mode). The surface of the sample is bombarded by 6-MeV alpha particles and x rays emitted by radioactive Curium-244 sources in the sensor head. The backscattered alpha particles are recorded by a thin alpha detector. The x rays are detected by a high-resolution silicon drift detector [3] that provides superior resolution (about 160 eV at 6.4 keV) compared to the Pathfinder APXS (260 eV). The x-ray mode is sensitive to major elements, such as Mg, Al, Si, K, Ca, and Fe, and to minor elements, including Na, P, S, Cl, Ti, Cr, and Mn. The alpha mode is very sensitive to C and O, and also to element groups of higher Z in vacuum. On the martian surface, there is an interference to C and O by the atmosphere which must be corrected for. The sampling depth is about 10 μm, with a detection limit of 0.5 to 1 weight percent depending on the element. The APXS is insensitive to small variations of the geometry of the sample surface because all major and minor elements are determined, and summed up to 100 weight percent.

Elemental Composition Determination: During the Pathfinder mission the rover approached many targets, including the rock "Barnacle Bill", which was the first martian rock ever analyzed. Many other soil and rock targets were visited during the rover mission (Fig. 1), which lasted significantly longer than expected. Depletion of the rover's primary batteries ultimately terminated APXS measurements, because the x-ray detector needed low temperatures (below -20 °C) during the night to operate satisfactorily.

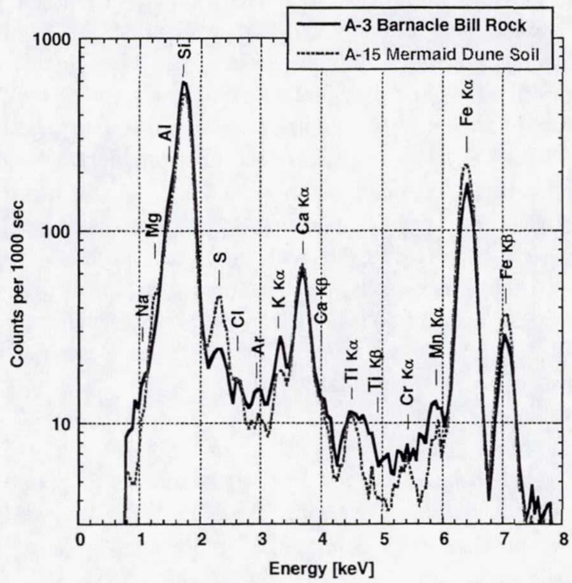

Figure 1 APXS x-ray spectra from Mars Pathfinder landing site: rock 'Barnacle Bill' and soil 'Mermaid Dune'.

Pathfinder APXS spectra were evaluated using several methods. In a first attempt, the peaks in the x-ray spectra were fitted using a Gaussian shape [1]. Later, their exact shape was derived, especially focusing on peculiarities of the detector response that resulted in spectral interferences produced by large peaks that lie close to weak peaks. This new method determined precisely the area of weak peaks in proximity to large ones. Similar improvements could be obtained for the spectral region in which the position of Mg, Al, Si, and P peaks are too close to be easily separated. The resolution of this region will be highly improved by the new detector and electronics in the Rosetta/Athena APXS.

Careful measurements were performed with an identical Pathfinder spare instrument under simulated martian atmospheric conditions. These measurements used certified geostandards and other validated materials, leading to improved re-calibration of the Pathfinder instrument. The quality of elemental composition of martian soils and rocks could be improved notably [4]. Also, the interference of the atmospheric component to the alpha spectra could be determined. Thus, the detection limit of carbon concentration (0.8 weight percent) was derived and, subsequently, no C could be detected in any of the martian samples.

Some Results from the Pathfinder Mission: Rocks at the Mars Pathfinder landing site are thought to have been deposited by catastrophic floods, originating in the ancient heavily cratered southern highlands. The APXS analyses of

the rocks yielded unexpectedly high Si and K concentrations, pointing to a highly differentiated crustal material in this region of Mars, similar to what is found on Earth (some authors classified the Pathfinder rocks as andesites or islandites). These results are in contrast to the concept of a rather mafic martian surface that was inferred from Viking soil data and the composition of martian meteorites

The soils at the Pathfinder landing site have similar compositions to those measured at the Viking sites. This is interpreted as being due to eolian global dust distribution, at least at low to middle latitudes. The most plausible interpretation for the high concentrations of S and Cl in the martian soil is the formation of sulfates and chlorides by the interaction of volcanic gases with the surface material. In general, the Viking soils were interpreted as weathering products of a mafic crustal material. However, Pathfinder APXS data lead to the proposal that the surface material consists of both mafic and felsic components [5].

Assuming that the soil is a mixture of two components, it was shown that taking the Pathfinder rocks as the felsic end member, the mafic end member is adequately represented by the martian meteorites. It was further shown that the two end members cover large surface areas as large geologic units.

The recently obtained TES (Thermal Emission Spectrometer) data of the Mars Global Surveyor orbiter support the above-mentioned model. The TES team [6] has reported that Mars can be divided into basaltic units covering most of the southern highlands and andesitic units restricted mainly to the northern hemisphere.

The refined method of peak search in the APXS x-ray spectra permitted the determination of phosphorous in soils and rocks at the Pathfinder site [7]. Surprisingly, only small differences of the P concentration between soils and rocks were found. A mean P content of about 0.3 % was obtained. The soils at Viking and Pathfinder landing sites have high and very similar sulfur and chlorine concentrations when compared to the rocks analyzed with the APXS [1]. The observed good correlation of S versus Mg, Si, Cl, K, and Ti for the Pathfinder samples apparently reflects the fact that sulfur-poor rocks are partly covered with sulfur-rich soils. The absence of a correlation of P with sulfur in all Pathfinder samples indicates no enrichment of P in the rocks compared to soil as was found for the other analyzed incompatible element potassium. Commonly, during magmatic fractionation processes P behaves as an incompatible element like potassium and chlorine. A lack of a correlation of P and K in the Pathfinder rocks would be more in accordance with a sedimentary origin of these rocks rather than an igneous origin. Therefore, the term 'andesite' should be replaced by 'silica-rich', to avoid potential misconception from a strict classification.

Instrument Performance: The Athena flight APXS will be fully tested over the expected operational temperature range, and will be extensively calibrated under ambient martian conditions using "pure element" targets, certified geostandards, and validated meteorites and terrestrial rocks.

The sensor head contains radioactive alpha sources (~40 mCi = 1.5 GBq Cm-244), two detectors (for alpha particles and X rays) with appropriate collimators for the definition of the spectrometer's "field of view", and preamplifiers for the detector signals. The collimation and the use of coated sources (which slightly reduce alpha particle energy) work together to reduce significantly the atmospheric interference that was suffered on Pathfinder.

The nominal working distance between sensor and sample is 40 mm and is defined by a rectangular apron whose end is brought into direct physical contact with the sample. At contact, two doors that otherwise protect the detectors open. The inner surfaces of the doors also serve as calibration targets. The nominal diameter of the area viewed is about 40 mm.

Instrument mass is 640 g (including 10% margin). The instrument uses 1.5 W of power when operating, and the sensor head is 80 mm long and 52 mm in diameter.

The APXS will be mounted on an instrument arm along with the other Athena in-situ instruments. The instruments will be used together to thoroughly characterize the elemental composition, mineralogy, and texture of martian rocks and soils.

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Safe Landings in Extreme Terrain

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Following the failure of the Mars Polar Lander and the re-evaluation of the Mars Sample Return mission status, a Safe Landing Tiger team was established on January 7, 2000. The charter of the team was to re-evaluate large scale (1000-2000 Kg) Mars lander designs with the principal objective being the assurance of safe landing in hazardous terrain. The tiger team developed a number of concepts, two of the most notable and promising concepts, are both based on a Mobile Lander paradigm. Unlike the Pathfinder and Surveyor class landers, this paradigm groups all of the landed equipment into one of two categories: EDL only equipment (ie not used after touchdown) and multi-use equipment, those used during and or after touchdown. The objective is to maximize the use of all equipment being brought to the surface by placing the bulk of the avionics and mechanical systems onto a much larger "rover" and leaving only the bare essentials on a "dead-on-arrival" landing system. All of the hardware that the surface roving mission needs is enlisted into performing the EDL tasks. Any EDL specific avionics not used after touchdown are placed on the landing system.

The first concept developed is called the pallet lander and is comprised of a low profile, large footprint mechanical framework which accommodates the descent propulsion system and a minimal set of avionics. The low profile of the pallet and the large scale of the Rover precludes the need ramps to allow rover egress. The basic principal of the pallet is that a lightweight semirigid central core takes the brunt of the primary impact, and in doing so is allowed to sustain irreversible but controlled damage. The rover is suspended above the core on 6 crushable shock struts. A reasonable analogy is that of a passenger car which sacrifices the vehicles integrity in order to protect the occupant (payload). As such, most of the pallet mechanical system is designed only to the levels required to ensure a safe stable landing even though large portions of the structure may be damaged during the landing. To prevent tipover, 6 outriggers are extended horizontally from the cetral core and are stabilized by tension only cables. This combination provides an extremely lightweight tension-compression outrigger system that is used for tipover stabilization but not primary touchdown impact mitigation.

The second concept developed by the tiger team is an airbag concept based on Mars Pathfinder heratige. In this concept an airbag system is wrapped directly around the large rover without the use of an exoskeletal frame such as the Pathfinder tetrahedron. Without the aid of this frame to self-right the rover after touchdown, a soft-goods concept was defined to ensure that the rover would be capable of self righting itself after a random touchdown and rollout. In order to maximize Pathfinder heratige, lobe diameter and inflation pressures were kept the same. The resuling airbag configuration coupled with a liquid propelled descent stage is capable of surviving landings on the required terrains .

The terrain requirements set forth for the tiger team were based on the work done in reference [1]. This study defined 3 representative terrains models described as lightly, moderately and heavily cratered terrains. The models generated combinations of slope, rock size and rock abundance. The program extrapolated from this study that lightly cratered terrains were the most viable landing sites for near term exploration. The touchdown requirement that stemmed from this report represented a 97% worst case. It was a continuum bounded by a 1 meter high rock (2 meter diameter half buried) on a zero degree slope, up to a .5 meter high rock on a 30 degree slope.

Using ADAMS dynamic simulation software, a high fidelity model of the pallet lander has been generated. The airbag system has also been modeled using a gas-bag simulation code developed for Pathfinder. Based on results from these both systems are capable of safe landings on a 30 degree slope with a 1 meter high rock (this excedes the requirement) and touchdown velocities with very large margins.

The team is currently designing a 3/8 test models of the pallet lander and airbag rollover system. The models will be used to validate the concepts to allow the team to make a quantified assesment of which concepet to carry forward into full scale development.

References:

[1] Doug Bernard and Matt Golombek, Preliminary Look at Hazard Models for Mars Landing, JPL IOM 3412-00-020, March 2, 2000.

This work was carried out at the Jet Propulsion Laboratory, Califonia Institute of Technology under a contract with the National Aeronautics and Space Administration.

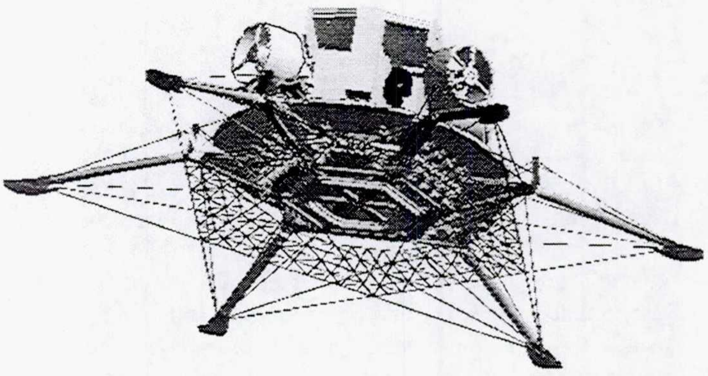

Figure 1: Bottom isometric view of pallet lander.

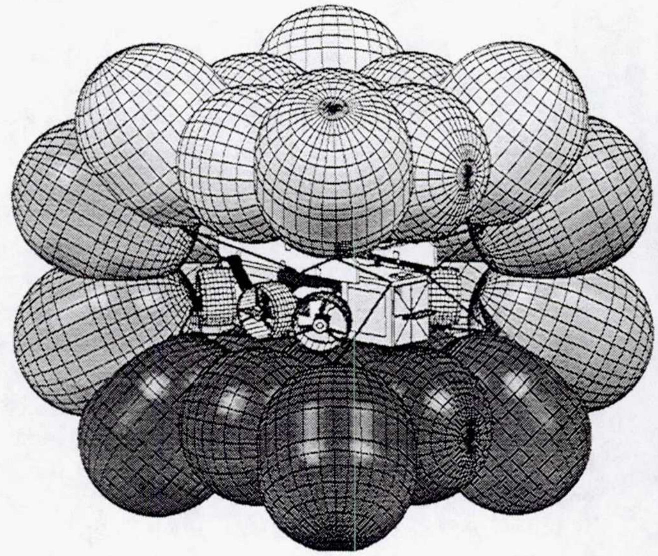

Figure 2: Isometric view of airbag landing system (2 bags removed for clarity).

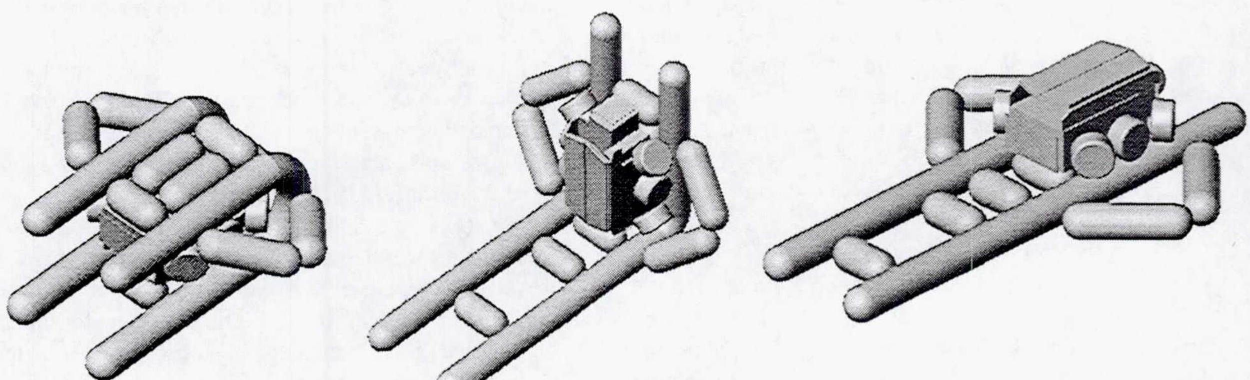

Figure 3: Inflatable self-righting system for the airbag lander (deflated impact bags not shown for clarity).

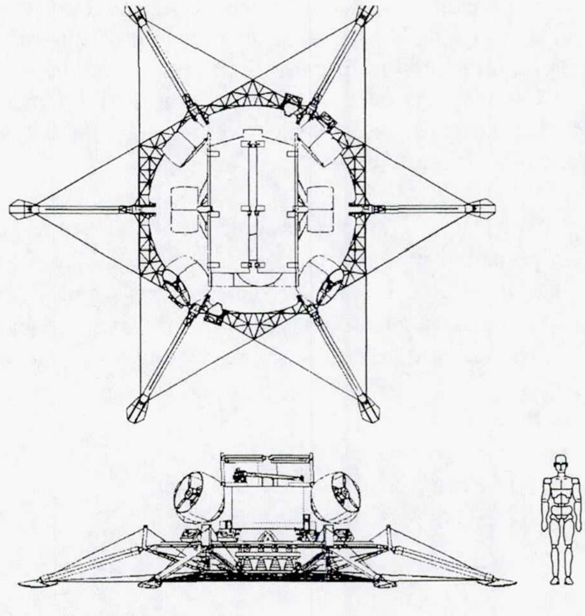

Figure 4: Top and front view of pallet lander.

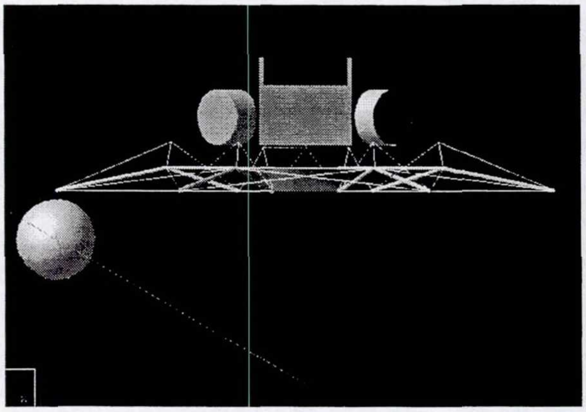

Figure 5: ADAMS simulation of pallet lander on a 30 degree slope with a 2 meter diameter rock half buried.

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MARS MOBILE LANDER SYSTEMS FOR 2005 AND 2007 LAUNCH OPPORTUNITIES. D. Sabahi, J.E Graf, Jet Propulsion Laboratories, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, (e-mail:dara.sabahi@jpl.nasa.gov)

Introduction: A series of Mars missions are proposed for the August, 2005 launch opportunity on a medium class EELV with a injected mass capability of 2600 to 2750 kg. Known as the Ranger class, the primary objective of these Mars mission concepts are:

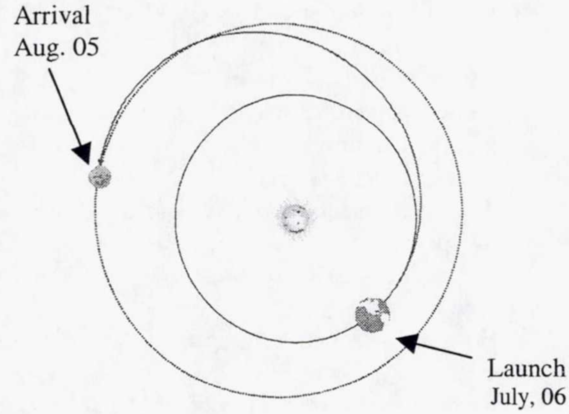
- Deliver a mobile platform to Mars surface with large payload capability of 150 to 450 kg (depending on launch opportunity of ' 05 or '07).
- Develop a robust, safe and reliable workhorse entry, descent & and landing (EDL) capability for landed mass exceeding 750 kg.
- Provide feed forward capability for the '07 opportunity and beyond.
- Provide an option for a long life telecom relay orbiter.

A number of future Mars mission concepts desire landers with large payload capability. Among these concepts are Mars sample return (MSR) which requires 300 to 450 kg landed payload capability to accommodate sampling, sample transfer equipment and a Mars ascent vehicle (MAV). In addition to MSR, large insitu payloads of 150 kg provide a significant step up from the Mars Pathfinder (MPF) and Mars Polar Lander (MPL) class payloads of 20 to 30 kg. This capability enables numerous and physically large science instruments as well as human exploration development payloads. The payload may consist of drills, scoops, rock corers, Imagers, spectrometers, in-situ propellant production experiment, and dust and environmental monitoring.

Mission Description: Mars ranger class landers (MRL) are high performance landers with long range roving capability, "dead on arrival" (DOA) landing gear with a mobile platform that can support a robust payload complement. Mars Rangers include a robust highly reliable entry, descent and landing (EDL) system with a large, multi-kilometer range mobile platform. Another option includes a cruise stage or a long life telecom orbiter accompanying the interplanetary phase of the mission.

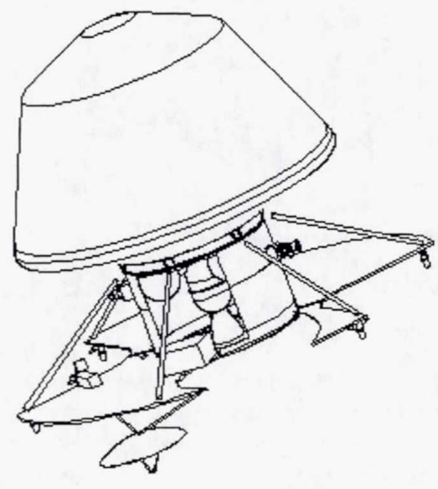
The Mars Ranger family of options have 3 key mission phases: cruise, EDL, and surface.

Cruise Phase : For the '05 opportunity, all missions use a type-II transfer trajectory. Launch is in August of 05 with a three week launch window (with a C3 of 18 km^2/s). Arrival is in July of '06 at 1:00 PM local solar time, in late spring in the Northern Hemisphere. The cruise duration is 11 to 12 months.



Transfer Trajectory

The cruise phase utilizes a cruise stage with independent monoprop propulsion and optical navigation capability. The cruise phase delivers the entry vehicle containing the lander on a precision direct entry trajectory. For one option a relay orbiter replaces the cruise stage. The orbiter will perform orbit insertion maneuvers after lander separation. The primary objective of the orbiter is to provide telecom relay capability for the 2005 and future landed missions. The orbiter will also have an imaging capability utilizing the optical navigation camera.



Mars Range Network Cruise Configuration with Relay Orbiter

MARS MOBILE LANDER SYSTEMS: D. Sabahi and J.E Graf

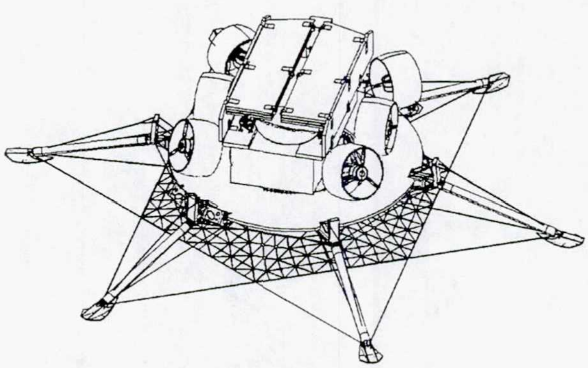
EDL Phase[1]: This is the most critical phase of the mission and requires significant technology development in order to meet reliable landing requirements.

The key EDL requirements are:

- 5.0-km landing radius
- 1.0-meter rock tolerance
- 30-deg slope tolerance
- < 2100 kg entry mass
- < 1500 kg landed mass

The EDL system meets and exceeds the above requirements by utilizing robust entry, descent and landing subsystems. The EDL system utilizes the following key subsystems:

- Entry vehicle with aeromanuver capability for enhanced performance.
- Subsonic parachute in addition to supersonic parachute for enhanced performance.
- Hazard avoidance capability for increased reliability.
- Throttled powered descent engines to increase reliability.
- A pallet or airbag with self-righting landing system for increased reliability[2].
- Avionics redundancy, selective cross-strapping and hot backup for increased reliability.
- X-band direct-to-Earth semaphores and UHF real time telemetry relay to an orbiting asset.



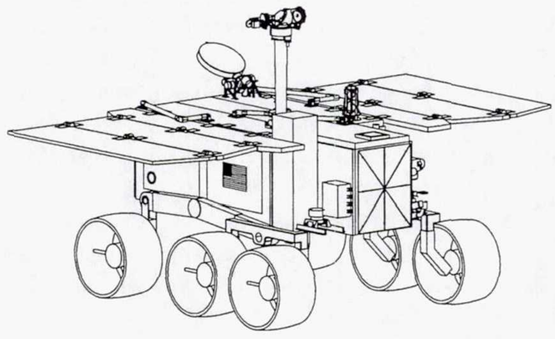
Lander/Rover Concept on Pallet Landed Configuration

Surface Phase[3]: The surface mission is a 90-sol mission with 90-sol extended mission goal. The surface mission will be in a latitude band of 5^{O} to 25^{O} North. A solar conjunction will occur 60-sols into the landed mission from October 13 to November 2.

The MRL concepts are known in the Summary matrix. One, called the Range Rover, employs a cruise stage that is discarded after separation. The lander supports up to seven instruments and has the volume and interfaces required for a MAV. Another, called the seeker is similar to the Range Rover, except it is smaller in size and cannot accommodate a MAV. The third, called Tracker has a relay orbiter instead of a cruise stage and can support up to seven instruments but no MAV. ity.

In all options the rover utilizes X-band direct to Earth telecom link and UHF relay link to an orbiting asset.

Additional options for the surface phase are under study. These options include stationary lander or multiple Rover configurations.



Mobile Large Rover with MAV Capability

Preliminary Mission Name	Mobile Lander	Cruise Stage	Orbiter	Instruments	MAV	Launch Vehicle
Range Rover	yes	yes	no	up to 7	capability only	Delta-4+ (5,4)
Seeker	yes	yes	no	up to 7	no	Delta-4+ (5,4)
Tracker	yes	no	yes	up to 7	no	Atlas-V 521

Mission Options Summary Matrix

Based on preliminary studies, all the options have generous resource margins as shown in the margin table below:

- Mass Margin 30% to 37%
- Power Margins > 45 %
- Battery SOC > 35 %
- Data Margin – X-Band 25%
- Data Margin X-band+UHF >200%
- Landing Velocity Margin 4 times
- Propellant Margin 30%
- Surface Life Margin 100%

References: [1] Thurman, S. W., (2000) LPI Workshop, Houston, TX. [2] Rivellini, T. P., Ortiz, G. M. and Steltzner, A. D. (2000) LPI Workshop, Houston, TX. [3] Eisen, H. J., (2000) LPI Workshop, Houston, TX.

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COMMON IN-SITU CONSUMABLE PRODUCTION PLANT FOR ROBOTIC MARS EXPLORATION.

G. B. Sanders, J. R. Trevathan, T. A. Peters, and R. S. Baird. NASA/Johnson Space Center

Introduction: Utilization of extraterrestrial resources, or In-Situ Resource Utilization (ISRU), is viewed by the Human Exploration and Development of Space (HEDS) Enterprise as an enabling technology for the exploration and commercial development of space[1]. A key subset of ISRU which has significant cost, mass, and risk reduction benefits for robotic and human exploration, and which requires a minimum of infrastructure, is In-Situ Consumable Production (ISCP). ISCP involves acquiring, manufacturing, and storing mission consumables from in-situ resources, such as propellants, fuel cell reagents, and gases for crew and life support, inflation, science and pneumatic equipment.

One of the four long-term goals for the Space Science Enterprise (SSE) is to "pursue space science programs that enable and are enabled by future human exploration beyond low-Earth orbit – a goal exploiting the synergy with the human exploration of space"[1]. Adequate power and propulsion capabilities are critical for both robotic and human exploration missions. Minimizing the mass and volume of these systems can reduce mission cost or enhance the mission by enabling the incorporation of new science or mission-relevant equipment. Studies have shown that in-situ production of oxygen and methane propellants can enhance sample return missions by enabling larger samples to be returned to Earth or by performing Direct Earth Return (DER) sample return missions instead of requiring a Mars Orbit Rendezvous (MOR). Recent NASA and Department of Energy (DOE) work on oxygen and hydrocarbon-based fuel cell power systems shows the potential of using fuel cell power systems instead of solar arrays and batteries for future rovers and science equipment. The development and use of a common oxygen/methane ISCP plant for propulsion and power generation can extend and enhance the scientific exploration of Mars while supporting the development and demonstration of critical technologies and systems for the human exploration of Mars.

In-Situ Propellant Production Sample Return Mission: Numerous studies have shown that the benefit of making propellants on Mars versus bringing them from Earth increases with corresponding increases in desired sample size or mission delta-V requirements. Since propellant mass typically makes up 60 to 80% of the ascent or Earth return vehicle mass, ISPP on the Mars surface can reduce the initial mission mass required in low Earth orbit by approximately 20% to 30% as compared to carrying all required propellant to the Mars surface from Earth. An even greater leverage can occur for Mars missions when in-situ water can be processed.

Over the last several years, the Johnson Space Center (JSC) has performed joint and independent mission and process trade studies for robotic ISPP sample return and human Mars missions, examining both propulsion and propellant production options. Even though there are numerous processes to convert Mars atmospheric carbon dioxide (CO_2) into oxygen (O_2) and other useful products, trade studies based on complexity, performance, and technology readiness currently show that the Sabatier/Water Electrolysis (SWE) process combined with the Zirconia CO_2 Electrolysis (ZCE) process to make O_2 and methane (CH_4) is the preferred propellant production option if Earth supplied hydrogen (H_2) is used. The SWE is a two-step process. First H_2 and CO_2 are fed into the Sabatier reactor at 250 C to produce CH_4 and water (H_2O). Then the H_2O is electrolyzed into O_2 and H_2, and the H_2 is recycled and combined with Earth or Mars supplied hydrogen to make more CH_4. Since the SWE process produces O_2 and CH_4 at a 2:1 mass ratio with Earth supplied H_2, and propulsion systems require a >3:1 mass ratio, an extra oxygen generation step (such as the ZCE) is required. The ZCE is a solid state ceramic device that combines the effects of high temperature (>800 C) and the presence of a catalyst to dissociate CO_2 into oxygen ions and carbon monoxide. The oxygen ions produced are conducted through the porous zirconia membrane with a voltage potential and combined into oxygen molecules on the opposite side of the membrane. Depending on sample size and ascent vehicle Delta-V requirements (MOR vs DER), a production rate of approximately 0.5 to 4 kg of propellant per sol for 300 to 500 days is required.

An area of chemical processing technology currently under development that can significantly reduce the mass, volume, and power of ISCP and fuel cell reagent processing systems, and thereby further reduce the mass and volume associated with ISCP-based robotic missions, is microchannel chemical/thermal system (MCTS) technology[2]. The use of microchannel and etched-plate fabricated reactors, heat exchangers, mixers, and separators allows for rapid heat and mass transport, improved temperature and reaction kinetic control to produce non-equilibrium chemical products, reduced gravity environment effects (since surface forces dominate over gravity forces), high productivity per unit volume, and enhanced thermal integration for energy efficiency without a reduction in throughput compared to conventional chemical processing systems. Preliminary system analyses by JSC and

DOE/Pacific Northwest National Laboratory (PNNL) show a factor of four reduction in mass and an order of magnitude reduction in volume compared to the baseline SWE and ZCE system.

Fuel Cell Powered Rovers & Science Equipment With In-Situ Produced Reagents: The SSE Mars Surveyor Program currently utilizes solar arrays and batteries to power landers and rovers. While relatively simple and successful, solar array/batteries do have some disadvantages, such as low energy capabilities, limited rover size, and daylight only (6 to 8 hours) operations. The current reference mission for human exploration of Mars assumes the use of a nuclear reactor to supply power to the ISCP plant and human habitat, and a Radioisotope Thermoelectric Generator (RTG) to power rovers for surface exploration. In an effort to investigate non-nuclear power options for human exploration, and to extend robotic surface operations, the use of fuel cells instead of solar arrays/batteries for robotic outpost rovers and science equipment is currently under investigation. JPL Team X and JSC completed a top-level trade study (Nov. 1999) comparing the capabilities of a solar array/battery powered rover against a high-pressure H_2/O_2 fuel cell powered rover. The fuel cell rover consisted of a rover vehicle with a Proton Exchange Membrane fuel cell (100 W to 200 W), and O_2, H_2, and H_2O tanks, and the lander included similar storage tanks and an electrolysis unit to convert H_2O into high-pressure O_2 and H_2. For the fuel cell rover to recharge, it has to return to the lander, and exchange water produced during electrical generation with new fuel cell reagents. The fuel cell enabled continuous roving operations, lights for nighttime operation, and use of power intensive science instruments. The study showed that selection of solar arrays/batteries versus fuel cells is based primarily on mission requirements, such as allowable rover size, desired mission operations (short vs long surface stays and daylight vs continuous operations), and science instrument power requirements. Solar array/battery power generation best supports size constrained rover missions with long duration surface stay times to compensate for lower science instrument power and daytime only operations.

Based on MCTS fuel processing and man-portable power generation development activities at PNNL and in-situ production of oxygen and methane development within NASA, JSC is currently examining a fuel cell powered robotic rover mission based on technology and systems under development for a Mars sample return mission utilizing ISPP. Initial calculations show that little modification to the sample return propellant production, liquefaction, and storage hardware and production rate would be required to support a fuel cell powered rover for a robotic outpost mission.

Current ISCP Development Activities: JSC is currently coordinating and focusing the Agency's development of ISCP technologies and systems for robotic and human exploration[3]. The goal of this program is to develop and validate ISPP technologies and systems to support a Mars ISPP sample return mission in 2007.

The SWE process for ISPP has primarily been developed by Lockheed Martin Astronautics with support from Hamilton Sundstrand. This chemical processing system was originally built and tested for NASA from 1994 to 1996, and has since been modified and upgraded by both LMA and JSC to operate under simulated Mars surface conditions. JSC is currently testing this unit, and is working on designing a second generation SWE system based on enhanced technologies and lessons learned. For the ZCE, both the University of Arizona (UofA) and Allied Signal have developed and tested the most advanced ZCE technology to date. The Oxygen Generator Subsystem on the Mars ISPP Precursor (MIP) flight experiment (originally manifested on the 2001 Mars Surveyor Lander) incorporates a single UofA (1" dia.) ZCE cell, and the recently selected PROMISE flight experiment will incorporate two 3-cell (2" dia.) stacks based on the MIP design. Allied Signal has built and tested the only multicell ZCE stack to date. MCTS technology has been under development at PNNL for several years for automotive fuel cell processors and man-portable power generation and thermal control units under DOE and Department of Defense (DOD) funding. Researchers at PNNL and JSC, under a currently funded 3 year effort, are collaboratively developing MCTS technology for Mars ISPP applications.

Conclusion: A common ISCP plant to produce oxygen and methane can enhance both Mars sample return and rover science missions while supporting the development and demonstration of critical technologies for the human exploration of Mars. Based on continuing development of the technologies and processes identified, science missions as early as 2007 can be supported with minimal program and mission risk.

[1] NASA Strategic Plan, 1998, NASA Policy Directive-1000.1.

[2] Wegeng, R., Sanders, G., "Microchemical and Thermal Systems for In Situ Resource Utilization", LPI No. 963, Feb., 1999

[3] Sanders, G. B., "ISRU: An Overview of NASA's Current Development Activities and Long-Term Goals", AIAA 2000-1062, 38th Aerospace Sciences Meeting, Reno, NV., Jan. 2000

TOOLS FOR ROBOTIC IN SITU OPTICAL MICROSCOPY AND RAMAN SPECTROSCOPY ON MARS. C. H. Schoen[1] and D.L. Dickensheets[2], [1]Detection Limit, Inc. (555 General Brees Rd. Laramie, WY 82070), [2]Montana State University (610 Cobleigh Hall, Bozeman, MT 59717).

Robotic missions to Mars require remote diagnostic tools for detecting evidence of former life. Laser Raman spectroscopy is eminently suitable for this quest as its light-scattering principle permits non-intrusive analysis. Integration of Raman spectroscopy with optical microscopy correlates biochemical and morphological data. Vibrational Raman spectra identify component moieties of unknown target biomolecules such as pigments involved in photosynthesis and UV-protection. Antarctic desert analogues of potential early Mars habitats support localized anaerobic photosynthetic bacteria and widespread cyanobacteria containing chlorophyll as a primary pigment. Chlorophyll and accessory pigments (e.g. phycocyanin) autofluoresce at visible wavelengths (e.g. 530 nm). Although valuable for epifluorescence microscopy, this interferes with Raman spectra by producing curved baselines and instrument saturation. Fourier Transform Raman spectroscopy (FTRS) with near-IR excitation avoids most fluorescence while producing distinct and unique spectra for a wide range of wavenumbers. These spectra identify key moieties, such as the porphyrin nucleus of chlorophyll, which can be detected in whole communities from deserts with features common to potential habitats of early Mars.

FTRS requires a heavy interferometer-based detector. Dispersive Silicon CCD detectors are much smaller but not sensitive at 1064 nm. Excitation at 852 nm is a CCD-compatible compromise. Although currently lacking the clarity of 1064 nm spectra, it avoids the substantial fluorescence induced by lasers at shorter wavelengths (e.g. 633 nm).

Figure 1 illustrates Raman spectra of *Acarospora chlorophana*, a yellow-pigmented epilithic desert lichen from Victoria Land, Antarctica. Spectra from the same specimen were compared with a bench-top 1064 nm FTRS instrument and a miniature 852 nm confocal microscope/Raman spectrometer system (mass <1 kg), under development with NASA funding for potential Mars landers and shown in Figure 2. Its small probe head (< 100 cm^3) contains the confocal microscope and Raman filters, fiber-coupled to the laser light source and spectrometer housed in an electronics bay. The confocal microscope (imaging at video rates of 30 frames per second) comprises a Silicon microelectromechanical (MEMS) bi-axial scanning mirror, precision molded aspheric lenses and piezoelectric focus control. The light source for both components is an 852 nm distributed Bragg reflector diode laser. Rayleigh scattered light is detected to form the confocal image, while Raman shifted light is separated by a Raman filter set and detected with a dispersive CCD-based compact spectrometer. Spectral resolution is 8 cm^{-1} over a range from 400 cm^{-1} to 1800 cm^{-1}. Raman spectra may be obtained over a variable field-of-view by controlling scanning in the microscope, from a minimum spot size of 1 μm to full field of 250 μm ×

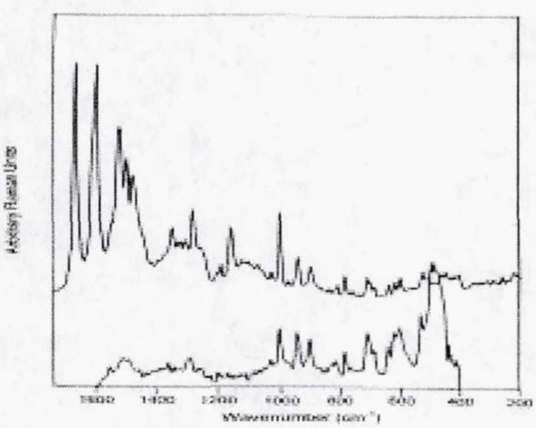

Figure 1 Raman spectra of *Acarospora chlorophana*. Top trace from 1064 nm FT-IR spectrometer (Bruker IFS66). Bottom trace from 852 nm dispersive CCD spectrometer.

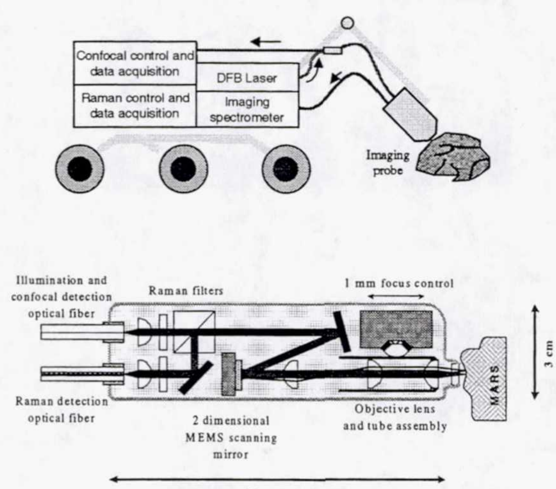

Figure 2. Miniature Confocal Microscope and Raman Spectrometer

250 µm. . The 852 nm spectrum here was obtained while scanning a field measuring 60 µm × 100 µm with incident power of 20 mW for a duration of 300 seconds and a total energy dose of 6 Joules. Figure 3 shows a confocal microscope image with accompanying spectra for a Calcite sample.

Of particular interest is a newly developed and patented dispersive 1064 Raman system utilizing volume holographic gratings and InGaAs arrays (Figure 4). Initial results show that the S/N is equivalent to that of the 852 nm system that uses a silicon based CCD array. In addition, the fluorescence problems that plague Raman systems using shorter wavelengths (including 852 nm) when analyzing many biomolecules are avoided with a system operating at 1064 nm. These systems are being developed through Micron Optical Systems, Inc. in Norfolk VA, and promise the first 1064 nm system that will satisfy space size, weight and performance requirements.

We believe that future development efforts to realize in situ Raman spectroscopy coupled to optical microscopy will benefit from these recent advances to produce compact instruments for near IR spectroscopy and couple them to miniaturized optical microscopes.

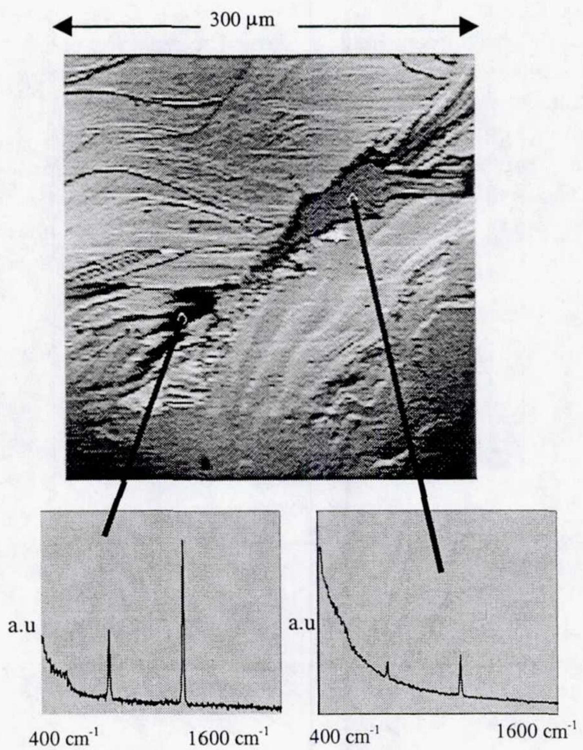

Figure 3. Confocal image of Calcite sample with point-specific Raman spectra, obtained with miniature 852 instrument.

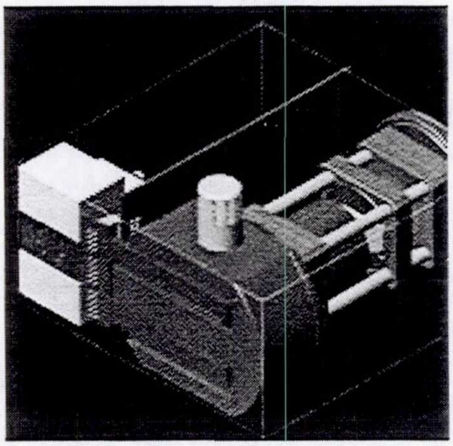

Figure 4 Combined 1064 laser/dispersive spectrometer assy < 1000 cm3.

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OPTICAL DATING OF MARTIAN EOLIAN SEDIMENTS BY ROBOTIC SPACECRAFT. Derek W. G. Sears[1], Kenneth Lepper[2], and Stephen W. S. McKeever[3]. Arkansas-Oklahoma Center for Space and Planetary Science, [1]Cosmochemistry Group, Dept. of Chemistry and Biochemistry, University of Arkansas, Fayetteville, AR 72701. Dsears@comp.uark.edu. [2]Environmental Science Program / Dept. of Physics, 145 Physical Sciences Bldg., Oklahoma State University, Stillwater, OK 74078. Lepper@okstate.edu [3]Dept. of Physics, 145 Physical Sciences Bldg., Oklahoma State University, Stillwater, OK 74078. u1759aa@okstate.edu.

Introduction: The Martian polar ice caps record a wealth of information about the past history and climate of Mars, but as pointed out by Clifford *et al.* in the summary of the *First International Conference on Mars Polar Science and Exploration* [1], "The single greatest obstacle to unlocking and interpreting the geologic and climatic record preserved at the [martian] poles is the need for absolute dating." Stratification in the polar caps arises, at least in part, from the incorporation of eolian material into the ice [2], and dune fields near the poles indicate eolian transport is an important surficial process in this region of Mars [3]. Eolian materials are ideally suited for sediment dating using luminescence methods. Luminescence dating techniques have been used successfully to make absolute age determinations for numerous terrestrial Quaternary eolian deposits. Clifford *et al.* [1] also concluded that cost, simplicity and potential for minaturization make luminescence dating more feasible than isotopic methods for *in situ* dating by robotic landers. In fact, the water detection equipment of the Deep Space 2 microprobes and the MECA on the Mars Polar Lander contain components similar to those required for luminescence dating.

Theoretical Considerations. Over geologic time, ionizing radiation from the decay of naturally occurring radioisotopes and from cosmic rays liberates charge carriers (electrons and holes) within silicate mineral grains. The charge carriers can subsequently become localized at crystal defects and are thus accumulated at these "electron traps". Recombination of the charge carriers results in photon emission, *i.e.* luminescence. The intensity of luminescence produced is proportional to the number of trapped charges, and thereby the time elapsed since trapping began. Experimentally, thermal or optical stimulation can be employed to liberate trapped charge producing thermoluminescence (TL) or optically stimulated luminescence (OSL), respectively. The response of the luminescence signal to ionizing radiation and the local ionizing radiation dose rate of the deposit must also be determined.

For successful application to dating, (i) the luminescence signal should increase monotonically with absorbed radiation dose, (ii) once promoted to traps, the electrons should remain trapped and not find ways of returning to the ground state, in other words the signal should be stable, and (iii) the signal should be essentially zero when the sediments are deposited so that the method actually determines the time interval since a physically significant event occured, namely the deposition of the grains.

The range of the method depends on mineralogy and local dose rates, but is typically ~1ka BP to ~150ka BP. Pore water in terrestrial sediments attenuates the external radiation dose which has the effect of extending the this accessible age range. The attenuation effect of the water ice and carbon dioxide ice of the Martian ice caps and the local ionizing radiation dose rates are unknown but amenable to laboratory experiments.

Reviews of the development of luminescence dating, and detailed discussions of procedures and limitations can be found in the references [4,5]. We have been exploring these questions and investigating the potential of luminescence dating for use on robotic Mars landers. Here we describe some of our results.

Characteristics of Martian Eolian Sediments. Data from the Pathfinder mission indicates that surface materials on Mars are similar to terrestrial basalts and andesites [6]. The primary components of such rocks are pyroxene, calcic plagioclase, and biotite, but spectroscopy of the martian surface suggests the presence of significant amounts of poorly crystalline iron-oxides and clay minerals, reflecting the importance of chemical weathering of surface deposits [7]. In this case, secondary quartz would also be expected in the suface sediments [8]. The morphological similarity between terrestrial and Martian dunes suggests that martian dunes are composed of sand-sized grains [2]. Eolian material incorporated in the polar ice caps is poorly determined at present, but is believed to be sand and smaller particles [3].

Preliminary investigations of the Luminescence Properties of the Mars Soil Simulant JSC Mars-1. We have conducted a preliminary characterization of the fundamental luminescence properties of the JSC Mars-1 soil simulant. The results indicate that the bulk sample has a wide dynamic radiation dose response range (Fig. 1), with no unusual or prohibitive signal instabilities, and is susceptible to solar resetting (Fig. 2) [9]. These three properties form a stable base for future investigation of the material's utility for luminescence dating. Further research on JSC Mars-1, other terrestrial analogs and, perhaps, Martian materials is needed to develop luminescence dating procedures and protocols for remote application to Martian samples.

Optical Dating of Martian Eolian Sediments by Robotic Spacecraft.: D.W.G. Sears, K. Lepper, and S.W.S. McKeever

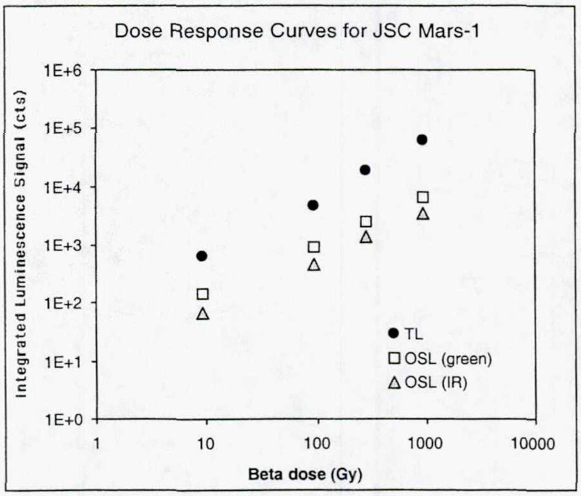

Fig. 1. Luminescence response to radiation dose for JSC Mars-1 soil simulant. Measurable dose response range exceeds that of terrestrial materials commonly used for luminescence dating.

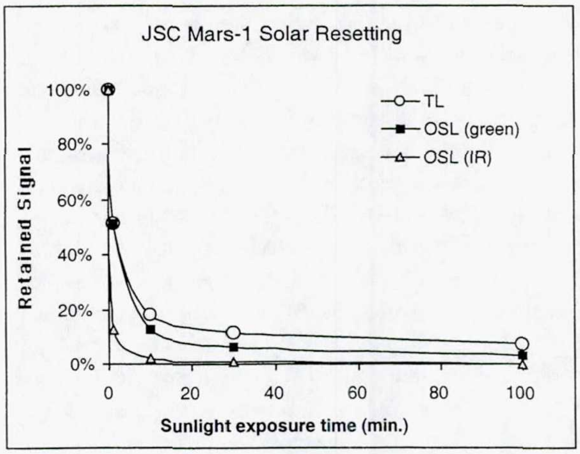

Fig. 2. Solar resetting curves for JSC Mars-1, shown as the percentage of luminescence signal retained after timed exposures to sunlight, exhibit responses typical of terrestrial materials commonly used for luminescence dating.

An *in situ* OSL dating experiment. We envision the development of DS2-like "dating-probes" or a deck-mounted luminescence dating module suitable for deployment by lander or rover on the surface of Mars. The essential elements of this system would include a sample collection device (similar to the soil auger aboard DS2), a sample chamber, an optical stimulation source (IR laser with filters and lenses), a light sensor (photodiode) and an irradiation source (*e.g.* a low level

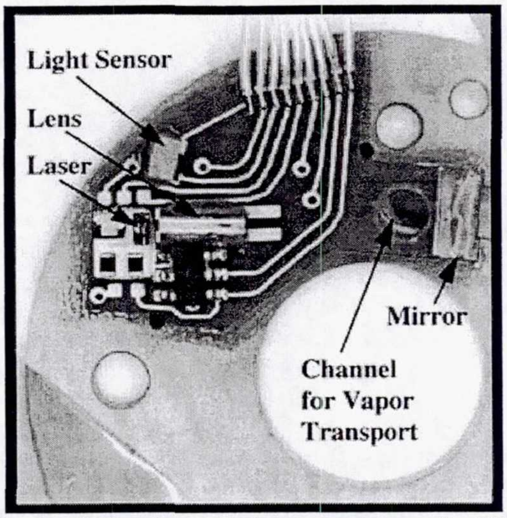

Fig. 3. Water determination apparatus on the DS-2 is very similar to that required for optical dating.

^{90}Sr β source). Many of these components already exist in the soil water detection experiment currently aboard the DS2 Mars microprobes (Fig. 3) and the MECA microscopy station on the Mars Polar Lander.

Also needed is a mechanism for determining the background radiation dose rate in the sample location. To do this we propose use of an OSL dosimeter probe consisting of, for example, carbon-doped sapphire [10] or silica glass doped with rare earth elements [11]. After exposure of the OSL dosimeter in the martian soil for a suitable period, the OSL signal can be read via stimulation with the IR laser.

With the components of such a system in place on a suitable platform (*i.e.* microprobe, lander, rover), a full OSL dating protocol could be carried out using procedures predetermined from laboratory experiments here on Earth. Data from the experiment would be transmitted to Earth where the age calculations would be performed. As an added bonus of this system, the OSL dosimeter will record the low-LET (<15keV μm^{-1}) dose absorbed during transit from Earth to Mars. Reading the OSL dosimeter upon arrival at Mars will reset the signal for *in situ* dosimetry and, at the same time, yield the Earth-Mars low-LET transit dose.

References: [1] Clifford S.M. et al. (2000) *Icarus* **144:** 210-242 [2] Greeley R. *et al.* (1992) *in* Mars *ed. Kiefer H. H. et al.* [3] Thomas P. et al. (1992) *in* Mars *ed. Kiefer H. H. et al.* [4] Aitken M. J. (1985) Thermoluminescence Dating. [5] Wintle A. G. (1997) *Radiation Measurements* **27:**769-817. [6] Rieder R. *et al.* (1997) *Science* **278:**1771-1774. [7] Soderbolm L. A. (1992) *in* Mars *ed. Kiefer H. H. et al.* [8] Gooding J. L. *et al.* (1992) *in* Mars *ed. Kiefer H. H. et al.* [9] Lepper, K. and McKeever, S.W.S. (2000) *Icarus* **144:**295-301. [10] Bøtter-Jensen L. and McKeever S.W.S. (1996) *Radiation Protection Dosimetry*, 65, 273-280. [11] Justus, B. *et al.* (1997) *Radiation Protection Dosimentry* **74:**151-154.

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Combined Remote Mineralogical and Elemental Measurements From Rovers. F. P. Seelos[1], R. C. Wiens[2], D. A. Cremers[2], M. Ferris[2], J. D. Blacic[2], and R. E. Arvidson[1], [1]Department of Earth and Planetary Sciences, McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130, seelos@wunder.wustl.edu, Tel: 314 935 4888, Fax: 314 935 4998, [2]Los Alamos National Laboratory, Los Alamos, NM 87545.

The FIDO/K9 Year 2000 Mars Prototype Rover field trials at the Lunar Crater Volcanic Field, Blackrock Summit, NV provided the opportunity for the tandem acquisition of Laser Induced Breakdown Spectroscopy (LIBS) data and VISIR reflectance data from select geologic targets in a non-laboratory environment [1]. The LIBS data were acquired by the LANL LIBS instrument mounted on the Ames Research Center K9 rover [2], and the VISIR reflectance data were acquired with an ASD Full Range portable spectrometer. The ASD instrument has a wavelength range of 350 to 2500 nm and a spectral resolution of 3 to 10 nm.

LIBS is focused on the determination of the elemental composition of a target, whereas VISIR reflection spectroscopy is more useful in inferring the mineralogy. By acquiring both types of data in tandem from rovers, a more complete characterization of the target can be obtained.

The samples that were measured in the field are pictured in Figure 1. It should be noted that sample A11/A14 is a single target separated into two pieces. In addition, the reflectance data for sample A04 proved to be unreliable so analyses are not included in this report. These considerations reduce the number of samples in the analysis to ten.

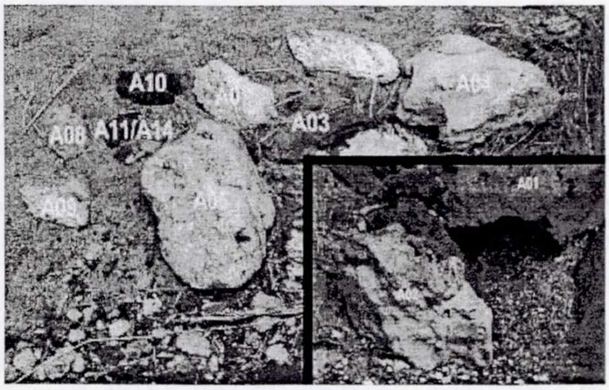

Figure 1 - Samples measured in the field with both the LIBS and reflectance instruments. Sample A05 is approximately eight inches long.

Analyses of the reflectance spectra led to the separation of the samples into four distinct groups. These groups are defined as follows: Group 1, Basalt endmember; low and generally featureless reflectance spectra. Group 2, Goethite endmember; characteristic goethite Fe^{3+} spectral features in the range of 0.50 to 0.85 microns. Group 3, Kaolinite endmember; diagnostic spectral doublet with minima at 2.17 and 2.21 microns. Group 4, Dolomite endmember; carbonate feature at 2.32 microns. It should be noted that many of the samples in Group 3 also exhibit the goethite spectral features, and that the lone sample in the dolomite group has a strong kaolinite doublet in its reflectance spectrum as well. Table 1 gives a summary of the results of the classification, and Figure 2 exhibits representative spectra from each group.

Group No.	Endmember	Member Samples
1	Basalt	A01; A10
2	Goethite	A03; A11/A14
3	Kaolinite	A05; A06; A07; A08; A09
4	Dolomite	A02

Table 1 - Groups determined from VISIR spectra.

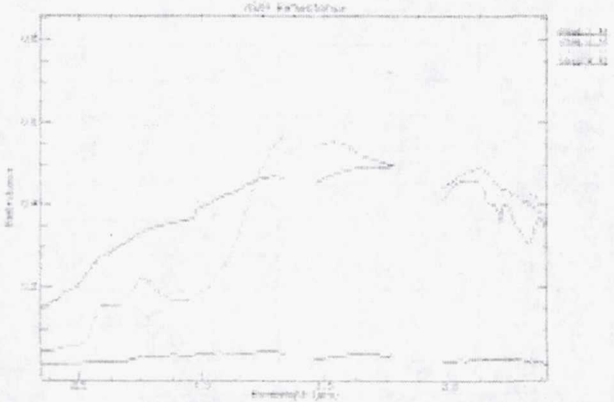

Figure 2 - Representative VISIR reflectance spectra.

The LIBS instrument operates by briefly illuminating a target with a powerful laser pulse that converts a small quantity of the target material to a plasma. This can be done from stand-off distances up to several tens of meters. The plasma that is created radiates in the visible spectrum, and is measurable with a spectrometer. From the spectroscopic data, the elemental composition of the target can be inferred [3].

Due to time constraints, the data acquired by the LIBS instrument in the field consisted only of single shot measurements that were effective over a wavelength range of 370-450 nm. In contrast, the preferred method of data acquisition consists of stacking multiple shots taken from the same target. Also in the

interest of time, no in-field composition calibrations were performed. Nevertheless, a great deal of information regarding the abundance of common rock-forming elements was recovered. In all cases, the LIBS data gave relative elemental abundances consistent with the endmembers that were identified from the VISIR reflectance spectra. The LIBS results are given in Table 2. It should be noted that the LIBS analysis was performed without any knowledge of the results from the VISIR spectra.

Combined VISIR/LIBS measurements thus allow for a much more accurate reconstruction of the chemistry and mineralogy of the samples than could be obtained by the analysis of either data set independently. A combined system could be used to great advantage during a rover mission to Mars, remotely acquiring mineralogical and elemental data for a large number of targets during traverses.

	Si	**Ca**	**Fe**	**Ti**	**Mg**	**Al**	**Sr**	**Na/ Ca**
	Group 1: Basalt							
A01	M	M-H	H	H	H	M-H		M-H
A10	M	M-H	M	M	M-H			M
	Group 2: Goethite							
A03	L	L	H					H
A11	L-M		H		H	L	H	M
A14	L	L	VH		M			
	Group 3: Kaolinite							
A05	VL	M-H			M	L	T	L
A06	VL	M-H			M	L	T	L
A07	M-H		L-M	M-H		M-H		H
A08	M			T		M-H		H
A09	M			T		M-H		H
	Group 2: Dolomite							
A02	VL	M-H			M	L	T	L

Table 2 - Relative elemental abundances from LIBS data. (VH: Very High, H: High, M: Moderate, L: Low, VL: Very Low; T: Trace)

References:

[1] Arvidson R. E. et al. (2000) . [2] Wiens R. C., et al. (2000) LPS XXXI, 1468. [3] Cremers D. A. and Radziemski L. J. (1986) in Laser Spectroscopy and its Applications (L.J. Radziemski, et al., eds), Chapter 5, Marcel Dekker, New York.

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THE MYTHS OF MARS: WHY WE'RE NOT THERE YET, AND HOW TO GET THERE. Donna L. Shirley, President, Managing Creativity

This paper is a controversial look at some of the beliefs (myths) held by the space community which block us from formulating a successful Mars Exploration strategy. The origins and consequences of these myths are presented in contrast with attitudes and actions which would have a better chance of getting us to Mars than we currently have.

Some examples of myths:

1. All it takes is guts and leadership:
   a. If a President would just declare.....
   b. If astronauts were willing to take risks.....

1a. was clearly disproved by the result of President George Bush's 1989 speech where he urged the U.S. to "go back to the Moon to stay....."and then on to Mars". Shortly thereafter Congress cancelled all funding not only for human Mars exploration, but also for robotic exploration.

As far as 1b, there are plenty of bold people (test pilots, Everest climbers, bungee jumpers) willing to take the personal risks. However, NASA and the US government have shown no willingness to risk large sums to fund a project (a la Bob Zubrin's Case for Mars) which is perceived to be risky without a compelling reason (e.g. a war).

2. NASA knows best:
   a. Werner was right.
   b. Apollo is the right model.
   c. Only NASA and its contractors (and international partners) can do the job.
   d. NASA <u>is</u> HEDS (Human Exploration and Development of Space).

2a and 2b share the belief that a program focussed solely on getting humans into space for the sake of exploration (or "missile flexing") will be fundable and is the right way to get there. The fact NASA has been unsuccessfully trying that approach since the early 1970's, but failing does not deter many from believing in its inherent correctness as a strategy. (All it takes is guts and leadership.....)

2c. precludes the vast majority of taxpayers from feeling a sense of real participation in the exploration of space, while 2d disenfranchises much of NASA, and especially discounts the role of robotic missions and the possible role of commercial enterprise.

3. If we tell the truth it won't sell
   a. The Shuttle
   b. The Station
   c. The Synthesis Group
   d. Mars Sample Return

3 a, b, c and d are all examples of where the cost of the project was either drastically understated or not stated at all. While this worked for the Shuttle and Station, it is unlikely to work for something as vast and visible as human exploration of Mars.

4. Only astronauts are interesting: Examples
   a. The Meatball eats all other NASA logos (except astronaut mission patches)
   b. NASA TV covers every minute of shuttle missions, even when nothing is happening.

The evidence, on the other hand, is that the public is quickly bored with astronauts unless there is something unusual about the mission (e.g. a woman commander or great danger). Whereas the Pathfinder landing and its record-setting web hits demonstrate that even a robotic mission with a gimmick (e.g. a cute rover) and interesting people will attract the public.

5. Scientists know best.
6. International participation saves money.
7. We can't risk astronauts' lives.
8. Etc.

What are some new paradigms that might serve us better in formulating a feasible Mars Exploration program? The following are examples.

1. Tell the truth
   a. About costs
   b. About capabilities
   c. About risk
2. Follow the money
   a. Recognize the power of a jobs program (a la Station)
   b. Nurture commercial and international efforts (but don't oversell them).
   c. Recycle Station components
3. Keep it interesting
   a. Robotic missions with fun stuff – not just good science
   b. Daily, wide-spread pictures, a la Hubble and Chandra
   c. Let other people play – for real! E.g. University student payloads or mission designs – taken seriously.
   d. Pursue more partnerships like Dreamtime.
4. Stay flexible
   a. Set aside some budget for targets of opportunity
   b. Take advantage of new technology – as actually demonstrated, not as "puffed".
   c. Use a "decision tree" program strategy

The paper will flesh out these new paradigms with specific suggestions. An example of a program architecture which reflects these paradigms will be presented.

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Advanced THEMIS for Orbital and Landed IR Imaging. S. Silverman[1], K. Blasius[1], and P. R. Christensen[2] [1]Raytheon Santa Barbara Remote Sensing, 75 Coromar Dr., Goleta, CA 93117, [2]Arizona State University, Tempe, AZ 85284,

Introduction: Advanced THEMIS is a project [1] to define and develop to breadboard stage, a miniature infrared imaging radiometer with applications to Mars orbiter and lander missions, as well as other planetary missions. The goal is to maintain or enhance functionality of the Thermal Emission Imaging System (THEMIS) now being built for the 2001 Mars Orbiter while reducing volume by ~75%. Other improvements expected are a broadened spectral range and improved radiometric calibration. A new generation of microbolometer detectors will be tested and further developed. These detectors have a new structure and smaller pitch, 25 microns vs. 50 microns used for THEMIS.

Advanced THEMIS will be a substantially smaller instrument than THEMIS, so it will reduce the cost of multispectral thermal emission imaging on future missions. Candidate missions include Mars Orbiter missions after 2003 and Mars lander-rover missions. The reduction in mass may greatly improve science return from these and other planetary missions. Advanced THEMIS offers opportunities for science return in two areas: surface mineralology and atmospheric phenomena, similar to the Mars Global Surveyor Thermal Emission Spectrometer now in operation [2].

Key Developmental Tasks: The realization of a highly capable Advanced THEMIS for Mars exploration is dependent on the outcome of three project tasks.

1. *Detector Spectral Response Characterization and Design Modifications.* We will characterize the spectral-radiometric response of the new 25μm microbolometer detectors developed by Raytheon Infrared Operations and investigate/implement design changes to improve sensitivity in specific regions of the spectrum. Response will be measured over the spectral range 1.0 to 30 μm.
2. *Detector Noise Characterization.* Uncooled microbolometer detectors have been developed primarily for terrestrial real-time imaging applications. These detectors typically operate at frame rates of either 30 Hz or 60 Hz. The pixel structure has been optimized to have short thermal time. For space remote sensing applications, it is often desirable to increase sensitivity by employing pixel averaging techniques, such as time-delay-and-integration (TDI), for sensors operating in a push-broom scanning mode, or frame-averaging. In either case the detectors must have good 1/f noise characteristics as well as low overall system drift in the output signal. This task will characterize the 1/f noise and output drift of the microbolometer detectors in order to determine the effectiveness of signal averaging.
3. *Radiometric Calibration Approaches.* Absolute IR radiometry requires two-point (gain and offset) calibration, while relative radiometric calibration requires at least single-point (offset) calibration. We will examine a variety of calibration approaches, including internal single and dual temperature references, external single and dual temperature references, partially transparent radiance references, ground truth, and combinations of the above.

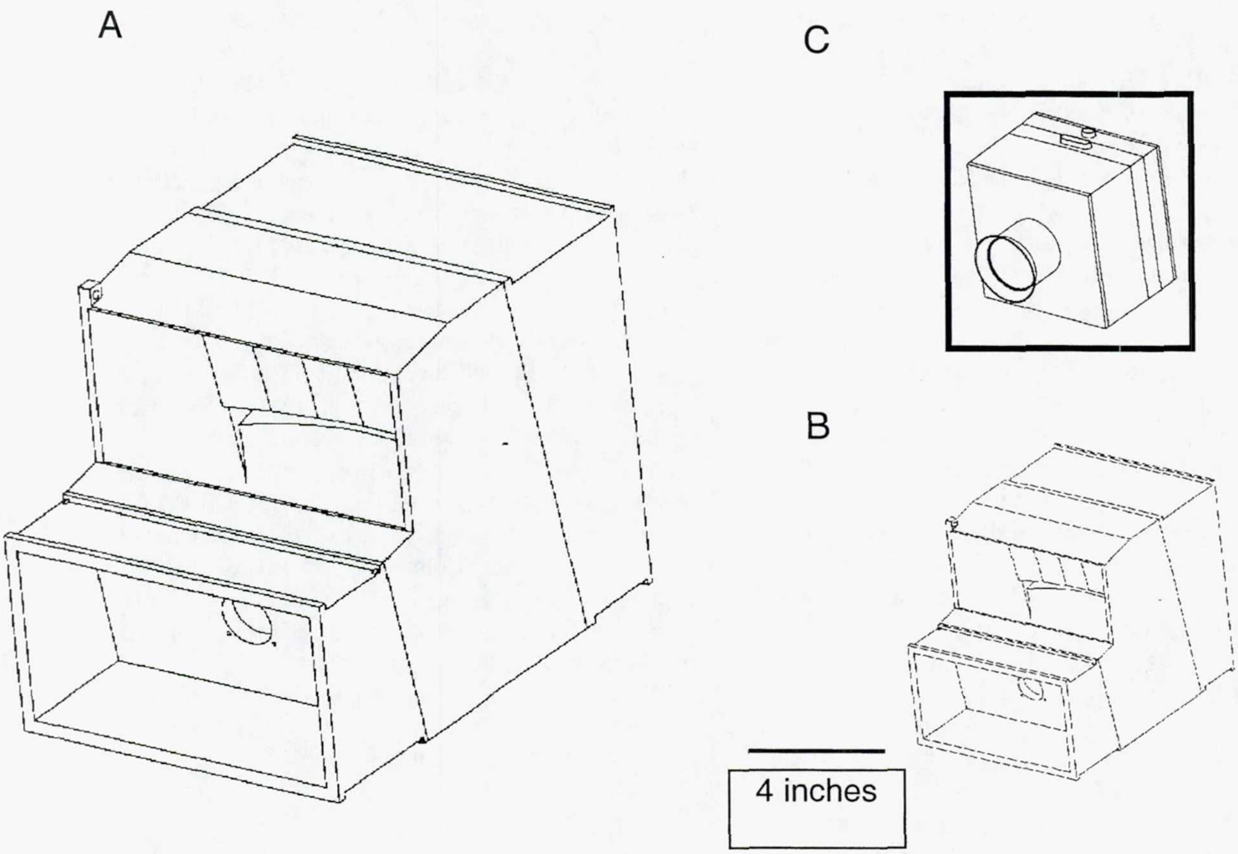
Instrument Concept: Advanced THEMIS is expected to allow future Mars orbiter and lander missions in the post-2003 era to perform multispectral thermal remote sensing of surface materials and atmospheric phenomena with lower launch and spacecraft costs. Table 1 is a comparison of estimated masses of a miniature Advanced THEMIS with THEMIS.

The shown reduction in mass of about 80% would make this Advanced THEMIS suitable for a low mass Mars Orbiter, balloon, aircraft, or rover payload. If only a limited IR spectral range is required, say 7 to 16 μm, and a shorter focal length can meet mission requirements, then the reflective telescope could be replaced with a refractive Ge lens for an additional savings of about 2 lbs. Figure 1. shows a pictorial comparison of THEMIS (A) with Advanced THEMIS concepts using reflective (B) and refractive optics (C).

References: [1] approved for funding in 2000 by NASA's Planetary Instrument Design and Definition Program [2] Christensen, P.R. (1992) JGR, 97, 7719-7734.

Table 1. Mass Budget Comparison Item	THEMIS Lbs.	Advanced THEMIS Lbs.
Refl. Telescope/Housing Assembly	9.7	2.4
Shutter Assembly	0.6	0.05
Electronics, electronics housing, and cables	10.2	1.5
Sunshade	1.6	0.4
Thermal Blankets	1.2	0.3
Misc. H/W, adhesives, etc	0.9	0.2
Total	**24.2 (w/o VIS camera)**	**4.9**

Figure 1. Scale of THEMIS (A) compared to Advanced THEMIS with refractive (C) and reflective (B) telescope optics.



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TMBM: TETHERED MICRO-BALLOONS ON MARS. M. H. Sims[1], R. Greeley[2], J. A. Cutts[3], A. H. Yavrouian[4] and M. Murbach[5], [1]NASA Ames Research Center, MS 269-3, Moffett Field, CA 94035, Michael.Sims@arc.nasa.gov, [2]Department of Geology, Arizona State University, Box 871404, Tempe AZ 85287-14045, Greeley@asu.edu, [3]Mars Program Office, Jet Propulsion Lab, 4800 Oak Grove Drive, Pasadena, CA 91109, james.a.cutts@jpl.nasa.gov, [4]Jet Propulsion Lab, 4800 Oak Grove Drive, Pasadena, CA 91109, andre.h.yavrouian@jpl.nasa.gov, [5]NASA Ames Research Center, MS 244-1, Moffett Field, CA 94035, mmurdoch@mail.arc.nasa.gov.

The use of balloons/aerobots on Mars has been under consideration for many years. Concepts include deployment during entry into the atmosphere from a carrier spacecraft, deployment from a lander, use of super-pressurized systems for long duration flights, "hot-air" systems, etc. Principal advantages include the ability to obtain high-resolution data of the surface because balloons provide a low-altitude platform which moves relatively slowly. Work conducted within the last few years has removed many of the technical difficulties encountered in deployment and operation of balloons/aerobots on Mars. The concept proposed here (a tethered balloon released from a lander) uses a relatively simple approach which would enable aspects of Martian balloons to be tested while providing useful and potentially unique science results.

TMBM would be carried to Mars on board a future lander as a stand-alone experiment having a total mass of 1-2 kgs. It would consist of a helium balloon of up to 50 m^3 that is inflated after landing and initially tethered to the lander. Its primary instrumentation would be a camera that would be carried to an altitude of up to tens of m above the surface. Imaging data would be transmitted to the lander for inclusion in the mission data stream. The tether would be released in stages allowing different resolutions and coverage. In addition during this staged release a lander camera system may observe the motion of the balloon at various heights above he lander. Under some scenarios upon completion of the primary phase of TMBM operations, the tether would be cut, allowing TMBM to drift away from the landing site, during which images would be taken along the ground.

The potential return from TMBM includes the following:

Science: Images with resolutions of 5 - 10 cm/pixel would be obtained for the landing site area, providing a critical link between images obtained from the lander and those available from orbit. These images would enable characterization and mapping of features such as small dunes forms, ripples patterns, wind-scours, and other surface structures indicative of the evolution of the Martian surface on sub-meter scales. Analyses of similar features at the Mars Pathfinder site have led to speculation of changes in wind regime through time which might relate to climate change; however, observations are limited in areal coverage and resolution. TMBM would afford the opportunity to test this and similar ideas by providing unique images. We note that images obtained during lander descent could provide similar coverage; however, obscuration by dust raised during descent could significantly degrade image quality. Moreover, the possible use of airbags on landers might make descent imaging difficult or impossible.

Operations: TMBM images would provide a critical base-map for lander operations by giving a context for measurements made from the lander. If a rover is part of the mission, TMBM images would enable planning near-term traverses from science and safety perspectives. The returned images will be mosaicked and structure from motion techniques will be used in the building of 3D terrain models of the landing area.

Technology: Balloons/aerobots of greater capabilities than TMBM could be implemented in further exploration of Mars. TMBM would enable validation of relevant technologies, including approaches and hardware for balloon deployment.

In summary, TMBM would be an excellent low risk addition to any lander mission beginning with the 2003 opportunities.

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Pgs 2

THE MARTIAN OASIS DETECTOR. P. H. Smith[1], M. G. Tomasko[1], A. McEwen[1], and J. Rice[1], [1]University of Arizona. Tucson AZ 85721, psmith@lpl.arizona.edu.

Introduction: The next phase of unmanned Mars missions paves the way for astronauts to land on the surface of Mars. There are lessons to be learned from the unmanned precursor missions to the Moon and the Apollo lunar surface expeditions. These unmanned missions (Ranger, Lunar Orbiter, and Surveyor) provided the following valuable information, useful from both a scientific and engineering perspective, which was required to prepare the way for the manned exploration of the lunar surface: (1) high resolution imagery instrumental to Apollo landing site selection also tremendously advanced the state of Nearside and Farside regional geology; (2) demonstrated precision landing (< 2 km from target) and soft landing capability; (3) established that the surface had sufficient bearing strength to support a spacecraft; (4) examination of the chemical composition and mechanical properties of the surface.

In terms of Martian exploration, we have achieved (Mariner, Viking, Mars Pathfinder) or are currently gathering (MGS) the following information necessary for Manned Mars Missions: imaging the surface at high resolution, soft landings, established that the surface will support a spacecraft, and conducted a cursory examination of the chemical composition and mechanical properties of the surface. Precision landings need to be achieved as well as surface mobility (10's km). This will be crucial for future unmanned scientific missions, especially sample return. Pinpoint landings and mobility will be required in order to collect the proper samples, i.e. lacustrine sediments, hydrothermal deposits.

Mars has a complex geological and perhaps a biologic history unlike the Moon. New analysis of MGS data indicate that the planet has been active recently in its geologic past (lava flows 10-40 mya, and fresh channels). This will present new but exciting challenges to both the unmanned and manned programs. For instance, a sample return mission will most likely be required to test for any potential harmful affects (chemical and biologic) to humans before sending astronauts. The geologic complexity of Mars, as evidenced in MOC imagery, will not be properly investigated and sampled by robotic missions. Manned expeditions to Mars will have to be conducted in order to fully understand and document the wonderfully complex geology of the surface and subsurface. Additionally, any thorough search for extinct and or extant life will have to be carried out by astronauts. This will involve great surface mobility, flexibility, deep subsurface drilling, and intelligence in the field.

The search for extinct or extant life on Mars will follow the water. However, geomorphic studies have shown that Mars has had liquid water on its surface throughout its geologic history. A cornucopia of potential landing sites with water histories (lakes, floodplains, oceans, deltas, hydrothermal regions) presently exist. How will we narrow down site selection and increase the likelihood of finding the signs of life?

One way to do this is to identify "Martian oases." It is known that the Martian surface is often highly fractured and some areas have karst structures that support underground caves. Much of the water that formed the channels and valley networks is thought to be frozen underground. All that is needed to create the potential for liquid water is a near surface source of heat; recent lava flows and Martian meteorites attest to the potential for volcanic activity. If we can locate even one spot where fracturing, ice, and underground heat are co-located then we have the potential for an oasis. Such a discovery could truly excite the imaginations of both the public and Congress providing an attainable goal for both robotic and manned missions.

The Martian Oasis Detector (MOD): The instrument required to detect an active oasis is a high spatial resolution (few tens of meters) Short Wavelength InfraRed (SWIR) spectrometer coupled with a high resolution camera (5 m/pixel). This combination creates too large a data volumn to possibly return data for the entire Martian surface; therefore, it has been designed as one of the first in a new generation of "smart" detectors.

It works in the following manner. A line of pixels centered on a strong water band is scanned across the surface and ratioed to another line of pixels in the nearby continuum. The results are quickly examined to answer the question: is there an overabundance of water vapor in a tiny spot compared to the local regional water content. In other words, is there evidence for a local source of water vapor? If the answer is yes, then we return all the data from that region as well as a high resolution image boresighted with the spectrometer. These data are then examined on the ground to make a final determination: likely candidates are re-observed to provide further evidence.

Naturally, this instrument can be commanded to fill the allowable data volume on pre-selected targets. It has the ability to detect hydrated minerals, iron oxides, silicates, anhydrous carbonates, evaporites, and ices. The high res imager can similarly improve our

knowledge of Martian features. But the unique contribution from this instrument is to find the water.

Detecting water vapor vents: If there is significant geothermal heat reaching the surface of Mars at the present time, there could be local regions where subsurface water is escaping from the surface of Mars at significant rates. The limiting rate is likely to be the rate at which water flows in to replace that lost in evaporation to the atmosphere. Note that the vapor pressure of water can be large compared to the surface pressure on Mars if the water is warm enough to exist in a liquid state just below the surface. The discovery of active vents would provide excellent places to look for signs of past (and possibly present) life on Mars.

Suppose there are small vents where water vapor is escaping into the atmosphere. Let the size of the vent be comparable to the spatial resolution of the SWIR (10s of meters). The column of water vapor will rapidly mix with the CO2 background atmosphere as it rises from the vent. Let the height of the column over which the average water vapor mixing ratio is 50% be H meters. The vertical abundance of water is about 3 cm-amagats per meter of height of the column. For low local wind speeds at the surface, the height H over which the water enhancement persists is likely to be several times the width of the source at the ground. For sources a few tens of meters across, the height H will be many tens to perhaps a few hundred meters. The abundance of water in the column will be 50 to a few hundred cm-amagats.

The background water abundance against which this absorption has to be detected is some 10 precip. µm, for instance, at an air mass factor of 3 at 4:30 pm local time. This corresponds to some 3.7 cm-amagats. Even if the background abundance is 3 times greater, it is much less than that in the water column over a small vent a few tens of meters across.

Figure 1 shows the curve of growth for the 1.38 µm water band for water vapor in the atmosphere of Mars. It shows that the absorption seen in the band is some 2.5% for the background water abundance of 10 precip. µm at an airmass factor of 3, while the absorption is some 10% in a column 100 m tall at 50% mixing ratio (airmass factor of 1) which also includes the backgroundwater vapor. The S/N ratio of the SWIR is 100 in a single pixel, and we can combine 7 pixels at the spectral resolution for which the curve of growth in Fig. 1 is shown. The S/N would be > 250 in the water band. A similar measurement would be made in a nearby continuum region. The absorption could then be measured to better than 150 S/N, so absorptions less than 1% can be measured. It is important for the continuum band close to the wavelength of the water band so that broad features in the reflectivity of the surface do not significantly modify the meaured band/continuum ratio. Fortunately, the reflectivity features in surface materials tend to be much broader than the feature seen in the atmospheric water bands at the low pressures on Mars.

Our plan is to compare the band/continuum ratio measured in individual pixel footprints on Mars with those of other regions across the track of the SWIR and with the running average along the track. When the local ratio exceeds the average ratio by an adjustable threshold factor (perhaps 3), we would trigger collection of an entire SWIR image cube and a high resolution CCD image frame for transmission to the Earth. At other times, the instrument would dump the data, and continue to search.

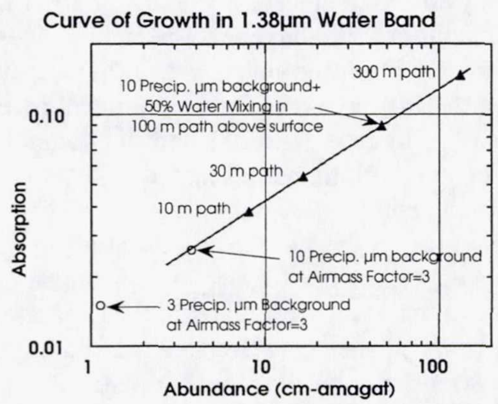

Figure 1. Absorption in 1.38 µm water band at the spectral resolution of the versus water abundance. The abundance of the background atmosphere (some 10 precip. µm at an arimass factor of 3) is shown, as is the total absorption for the background plus a column of 10m to 300m height at an airmass factor of 1 in which the water is mixed at 50% with the CO2 atmosphere. Absorptions of some 10% are seen for columns 100 m high compared to some 1.5% to 4% in case of background atmosphere having 3 to 30 precip. µm water at an airmass factor of 3.

At the present, no instrument has had the ability to detect the one substance that everyone agrees defines the Mars program. The Oasis Detector is the instrument of choice to find the active hydrothermal vents and reignite the Mars program.

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What scientific objectives have been defined by the French scientific community for Mars exploration?

Christophe Sotin, chairman of the solar system working group at CNES, Laboratoire de Planétologie et Géodynamique, Nantes, France

Every four or five years, the French scientific community is invited by the French space agency (CNES) to define the scientific priorities of the forthcoming years. The last workshop took place in March 98 in Arcachon, France. During this three-day workshop, it was clear that the study of Mars was very attractive for everyone because it is a planet very close to the Earth and its study should allow us to better understand the chemical and physical processes which drive the evolution of a planet by comparing the evolution of the two planets. For example, the study of Mars should help to understand the relationship between mantle convection and plate tectonics, the way magnetic dynamo works, and which conditions allowed life to emerge and evolve on Earth. The Southern Hemisphere of planet Mars is very old and it should have recorded some clues on the planetary evolution during the first billion years, a period for which very little is known for the Earth because both plate tectonics and weathering have erased the geological record.

The international scientific community defined the architecture of Mars exploration program more than ten years ago. After the scientific discoveries made (and to come) with orbiters and landers, it appeared obvious that the next steps to be prepared are the delivery of networks on the surface and the study of samples returned from Mars. Scientific objectives related to network science include the determination of the different shells which compose the planet, the search for water in the subsurface, the record of atmospheric parameters both in time and space. Those related to the study of samples include the understanding of the differentiation of the planet and the fate of volatiles (including H2O) thanks to very accurate isotopic measurements which can be performed in laboratories, the search for minerals which can prove that life once existed on Mars, the search for present life on Mars (bacteria).

Viking landers successfully landed and the surface of Mars in the mid seventies. Mars Pathfinder showed that rovers could be delivered at the surface of the planet and move around a lander. If it seems feasible that such a lander can grab samples and return them to the lander, a technical challenge is to launch successfully a rocket from the surface of Mars, put in orbit the samples, collect the sample in orbit and bring them back to the surface of the Earth. Such a technical challenge in addition to the amount of scientific information which will be returned, makes the Mars Sample Return mission a very exciting mission at the turn of the millenium. Following the Arcachon meeting, CNES made the decision to support strongly Mars exploration. This program includes three major aspects : strong participation in the ESA Mars Express mission, development of network science in collaboration with European partners, and participation in the NASA-lead Mars Sample Return mission. In addition, participation in micromissions is foreseen to increase the scientific return with low-cost missions.

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The Athena Mars Rover Investigation. S.W. Squyres[1], and the Athena Science Team (R.E. Arvidson, J.F. Bell III, M. Carr, P. Christensen, D. Des Marais, T. Economou, S. Gorevan, L. Haskin, K. Herkenhoff, G. Klingelhöfer, A. Knoll, J.M, Knudsen, A.L. Lane, V. Linkin, M. Malin, H. McSween, R. Morris, R. Rieder, M. Sims, L. Soderblom, C. d'Uston, H. Wänke, T. Wdowiak) [1]Cornell University, Ithaca NY 14853.

Introduction: The Mars Surveyor program requires tools for martian surface exploration, including remote sensing, *in-situ* sensing, and sample collection. The Athena Mars rover payload is a suite of scientific instruments and sample collection tools designed to: (1) Provide color stereo imaging of martian surface environments, and remotely-sensed point discrimination of mineralogical composition. (2) Determine the elemental and mineralogical composition of martian surface materials. (3) Determine the fine-scale textural properties of these materials. (4) Collect and store samples. The Athena payload is designed to be implemented on a long-range rover such as the one now under consideration for the 2003 Mars opportunity. The payload is at a high state of maturity, and most of the instruments have now been built for flight.

Imaging and Remote Mineralogy: The topography, morphology, and mineralogy of the scene around the rover will be revealed by *Pancam/Mini-TES*, an integrated imager and IR spectrometer. Pancam views the surface around the rover in stereo and color. The detectors are 1024×512 CCDs, and the electronics provide 12-bit analog-to-digital conversion. Filters provide 14 color spectral bandpasses over the spectral region from 0.4 to 1.1 μm. Narrow-angle optics yield an angular resolution of 0.31 mrad/pixel. Image compression is performed using a wavelet compression algorithm.

The Mini-Thermal Emission Spectrometer (Mini-TES) is a point spectrometer operating in the thermal IR. It produces high spectral resolution (10 cm^{-1}) image cubes with a wavelength range of 6-25 μm, a nominal signal/noise ratio of 450:1, and a maximum angular resolution of 8 mrad (8 cm at a distance of 10 m). The wavelength region over which it operates samples the diagnostic fundamental absorption features of rock-forming minerals, and also provides some capability to see through dust coatings that could tend to obscure spectral features. The mineralogical information that Mini-TES provides will be used to select from a distance the rocks and soils that will be investigated in more detail and ultimately sampled. Mini-TES is derived from the MGS TES instrument, but is significantly smaller and simpler. The instrument uses an 6.3-cm Cassegrain telescope, a Michelson interferometer, and uncooled pyroelectric detectors. Along with its mineralogical capabilities, Mini-TES can provide information on the thermophysical properties of rocks and soils. Viewing upward, it can also provide temperature profiles through the martian atmospheric boundary layer.

Elemental and Mineralogical Composition: Once promising samples have been identified from a distance using Pancam/Mini-TES, they will be studied in detail using up to three compositional sensors that can be placed directly against them by an instrument arm. The two compositional sensors presently built for flight are an *Alpha-Proton-X-Ray Spectrometer* (*APXS*), and a *Mössbauer Spectrometer*. The APXS is derived from the instrument that flew on Mars Pathfinder. Radioactive alpha sources and three detection modes (alpha, proton, and x-ray) provide elemental abundances of rocks and soils to complement and constrain mineralogical data. The Athena APXS has a revised mechanical design that will cut down significantly on backscattering of alpha particles from martian atmospheric carbon. It also includes a target of known elemental composition that will be used for calibration purposes. The Athena Mössbauer Spectrometer is a diagnostic instrument for the mineralogy and oxidation state of Fe-bearing phases, which are particularly important on Mars. The instrument measures the resonant absorption of gamma rays produced by a ^{57}Co source to determine splitting of nuclear energy levels in Fe atoms that is related to the electronic environment surrounding them. It has been under development for space flight for many years at the Technical University of Darmstadt. The Mössbauer Spectrometer (and the other arm instruments) will be able to view a small permanent magnet array that will attract magnetic particles in the martian soil. The payload also includes a *Raman Spectrometer*. This instrument will provide precise identification of major and minor mineral phases. It requires no sample preparation, and is also sensitive to organics.

Fine-Scale Texture: The instrument arm also carries a *Color Microscopic Imager* that will obtain high-resolution color images of the same materials for which compositional data will be obtained. Its spatial resolution is 30 μm/pixel over a 3-mm depth of field. It uses the same CCD detectors and electronics as Pancam

Sample Collection and Storage: Martian rock and soil samples can be collected using a low-power rotary coring drill called the *Mini-Corer*. This device can obtain intact samples of rock from up to 5 cm within

strong boulders and bedrock. Nominal core dimensions are 8×25 mm. The Mini-Corer drills a core to the commanded depth in a rock, shears it off, retains it, and extracts it. It can also acquire samples of loose soil, using a special tool designed for this purpose that can be fixtured to the tip of the drill.

The Mini-Corer can drill at angles from vertical to 45° off vertical. It has interchangeable bits for long life. Mechanical damage to the sample during drilling is minimal, and heating is negligible. After acquisition, the sample may be viewed by the arm instruments, and/or placed in a sample container.

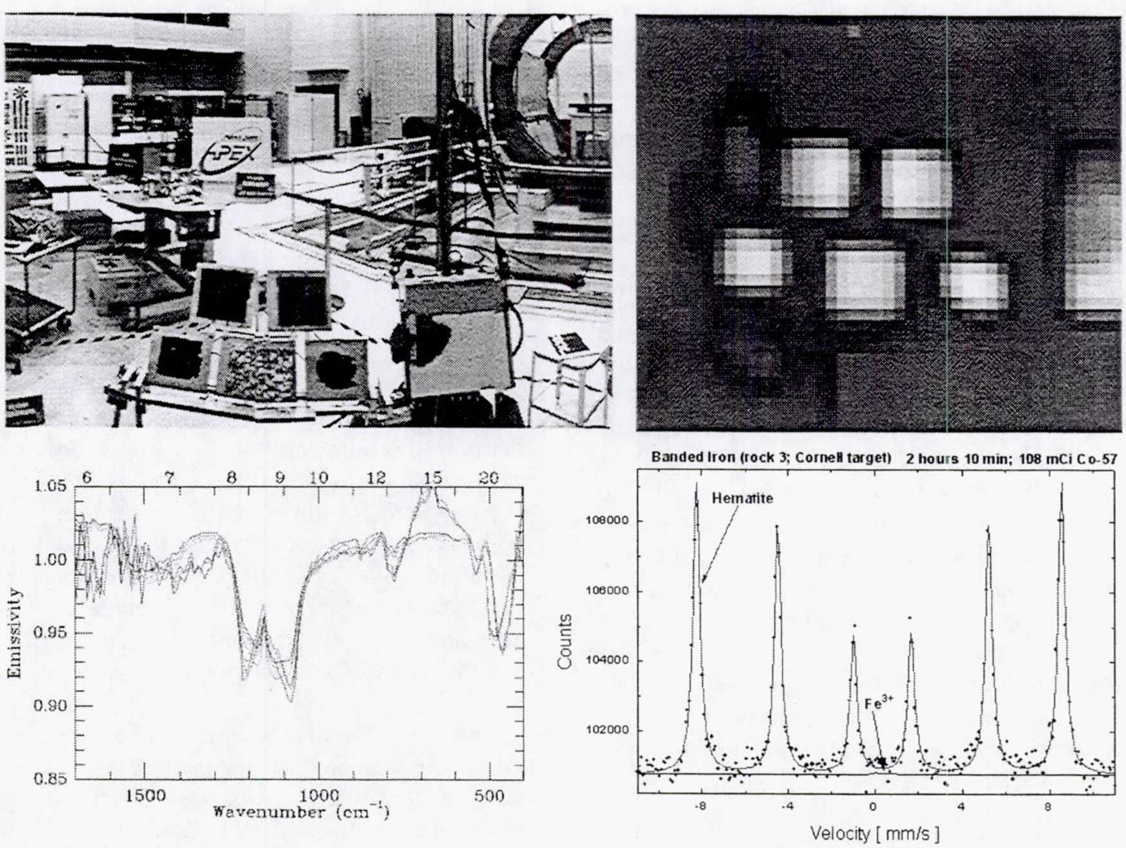
Payload Status: The Athena payload was selected for flight in November of 1997, and has been in development since that time. Flight-qualified versions of Pancam, Mini-TES, APXS, and the Mössbauer Spectrometer have now been built, calibrated, and tested for survival and operation in key flight environments.

The Color Microscopic Imager (CMI) will be built using an existing flight spare Pancam camera body. New optics are now in development for the CMI, as well as a redesigned filter wheel assembly that provides for both color imaging and active focus control.

An engineering model of the Mini-Corer has now nearly completed fabrication. For the Raman Spectrometer, several functional breadboards have been built and have demonstrated good performance. A detailed design for the Raman engineering model has been completed.

Payload Synergy: The Athena payload is specifically designed to be used as an integrated instrument suite. As the rover explores, the in-situ instruments perform detailed analyses of promising samples that are identified from a distance with Pancam and Mini-TES. Selected rocks and soils can then be collected using the Mini-Corer; use of the Mini-Corer also exposes fresh subsurface rock that can be examined by all the instruments. Recent tests have demonstrated the capabilities of the Athena flight instruments. Figure 1 shows some example data.

Figure 1: Data from recent tests of the Athena flight instruments. Cloclwise from top left: (1) Part of a Pancam panorama, showing a rock target in the foreground. (2) A Mini-TES image of the rock target (with a person sitting to the left of it); colors denote mineralogy. (3) A Mossbauer spectrum of one of the targets, showing the signature of hematite. (4) A Mini-TES spectrum of the same target, showing signatures of hematite and quartz.



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IN SITU RESOURCE UTILIZATION TECHNOLOGIES FOR ENHANCING AND EXPANDING MARS SCIENTIFIC AND EXPLORATION MISSIONS. K. R. Sridhar[1] and J. E. Finn[2], [1]Department of Aerospace and Mechanical Engineering, University of Arizona, Tucson, AZ 85721; [2]NASA Ames Research Center, M/S 239-15, Moffett Field, CA 94035.

The primary objectives of the Mars exploration program are to collect data for planetary science in a quest to answer questions related to Origins, to search for evidence of extinct and extant life, and to expand the human presence in the solar system. The public and political engagement that is critical for support of a Mars exploration program is based on *all* of these objectives. In order to retain and to build public and political support, it is important for NASA to have an integrated Mars exploration plan, not separate robotic and human plans that exist in parallel or in sequence. The resolutions stemming from the current architectural review and prioritization of payloads may be pivotal in determining whether NASA will have such a unified plan and retain public support.

There are several potential scientific and technological links between the robotic-only missions that have been flown and planned to date, and the robotic + human missions that will come in the future. Taking advantage of and leveraging those links are central to the idea of a unified Mars exploration plan. One such link is *in situ* resource utilization (ISRU) as an enabling technology to provide consumables such as fuels, oxygen, sweep and utility gases from the Mars atmosphere.

ISRU for propellant production and for generation of life support consumables is a key element of human exploration mission plans because of the tremendous savings that can be realized in terms of launch costs and reduction in overall risk to the mission. The Human Exploration and Development of Space (HEDS) Enterprise has supported ISRU technology development for several years, and is funding the MIP and PROMISE payloads that will serve as the first demonstrations of ISRU technology on Mars.

These payloads are critical building blocks toward the future use of ISRU. Many complicated systems, from the collection of atmospheric gases to the liquefaction and storage of propellants must be demonstrated on the Mars surface before they can be built for larger-scale missions. Ground-based testing is necessary and is being performed as completely as possible in simulated Mars environments, but it is not sufficient. There are two reasons for this:

- It is impossible to simulate adequately the environmental conditions on Mars to the degree necessary to achieve the required confidence level. There are many unknowns and variables in the surface conditions that can have a significant impact on the ISRU plant's operation. These include factors such as the physical, chemical, and electrical properties of dust; atmospheric composition; the diurnal temperature characteristics; the heat transfer environment; wind velocities; and the various weather cycles and patterns.

- An ISRU-based architecture will be a mission-critical element. It is simply inconceivable that a mission-critical element that has not been tested in the *real* environment will ever be baselined for a mission — robotic or human. Technology demonstrations of mission-critical elements are not a luxury, they are a necessity. The Thomas Young Committee report succinctly captures this philosophy by stating "test-as-you-fly, fly-as-you-test."

Clearly, flight demonstrations of ISRU technology are needed prior to human missions. How can such technologies benefit earlier, robotic science missions? There are several ways:

- Sample return.
- Power for surface mobility (roving and aerial vehicles).
- Nighttime heat and electricity production (regenerative fuel cells).
- Deep drilling projects.
- Utility and sweep gases for experiments.
- Science will demand that humans go to Mars.

In our discussion and presentation at the workshop, we will highlight how the PROMISE ISRU experiment that has been selected by HEDS for a future Mars flight opportunity can extend and enhance the science experiments on board.

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FIELD EXPERIMENTS WITH PLANETARY SURFACE ROVERS: LESSONS FOR MARS MISSION ARCHITECTURE. Carol Stoker, NASA Ames Research Center, M.S. 245-3, Moffett Field, CA 94035, cstoker@mail.arc.nasa.gov

Introduction: Over the last decade, a variety of field experiments have been performed that simulate operations of a rover on Mars [1,2,3,4,5,6]. These, in combination with the Pathfinder experience, lead to a realistic assessment of rover mission capabilities and to recommendations for rover technology and mission architecture to improve the science return of Mars exploration.

Table 1 summarizes field experiments that represent a range of possible mission designs and operational strategies. The experiments varied by the type and quality of imaging systems and other instrumentation, the use of orbital and aerial imaging and spectroscopy, the communication bandwidth and command strategy, and the distance traveled. All mission simulations were blind field tests operated by science teams whose interpretations were compared to field ground truth providing an assessment of the accuracy of remote science interpretations and a better understanding of where improvements are needed.

Table 1. Capabilities demonstrated on rover field experiments

Experiment	Orbital Data	Aerial Data	Rover Imaging	Rover Instruments	Ops. style	Comd. Cycles	Traverse Distance
Kilauea, 1995[1]	b&w 10m/pix	aerial overflight (film + prints)	color streaming video, frame-grab	arm camera	real time teleop.	NA	1.2 km (in 8 hrs)
Tuba City 1996 [2]	b&w 10m/pix	simulated descent (film + prints)	multispec. stereo 1mrad/pix	arm camera, sample scoop	single command, rapid feedback	70 (in 3 days)	100m
Pathfinder 1997 [3]	Viking,b&w >100m/pix	none	b&w. stereo 3mrad/pix	APX	command sequence, lander spots rover	80 (in 90 days)	100m
Silver Lake 1999 [4]	b&w 10m + 2m/pix, multispectral images (VNIR& TIR 10 m/pix)	simulated descent (b&w, digital images)	color stereo .3mrad/pix	VNIR spectra, TIR spectra, RAC	command sequence	16 (in 14 days)	40m
LunarCrater 2000	b&w 10m/pix	simulated descent (color digital images), AVARIS	color stereo .3mrad/pix	none	command sequence	12 (in 3 days)	60m

2001 Mission Field Test: One relevant mission simulation was performed in Silver Lake, California in 1999 (SL99)[4] using the Marsokhod rover. The payload (Descent Imager, PanCam, MiniTES, and Robotic Arm Camera), rover size and capabilities, data volumes, and command cycles simulated those planned for the Mars Surveyor mission originally selected for 2001which included a rover carrying the Athena payload [7] and a lander carrying a robotic arm and Robotic Arm Camera system [8]. The field rover carried a high resolution (.3mrad/pixel) color imager which simulated the Athena PanCam. A visible/near-infrared (VNIR) fiberoptic spectrometer (operating range 0.35-2.5μm), bore-sited with the left PanCam imager and an infrared spectroradiometer (operating range 8-14 μm) simulated the MiniTES Thermal Emission Spectrometer from the Athena payload. An engineering model of the Robotic Arm Camera selected for the 2001 lander was also used in conjunction with the excavation of a trench into the subsurface. The science team was provided with simulated images from the Mars Descent Imager selected for the 2001 lander, simulated Mars Orbiter Camera (MOC) images, and multispectral images similar to those expected from the 2001 orbiter THEMIS instrument obtained with the airborne Thermal Infrared Mapping Spectrometer. Commands sequences were sent daily to the rover and data returned were limited to 40 Mbits per

communication cycle. Figure 1 shows the science sites visited during this simulation, referenced to a simulated MOC-resolution oribtal image. During the 14 day simulated mission, 16 commands were uplinked to the rover, it traversed ~ 40 meters, 6 sites were analyzed, 11 samples were collected for laboratory analysis, and over 5 Gbits of imaging and spectral data were collected. Remote science interpretations from 22 participants were compared with ground truth from the field and laboratory analysis of collected samples.

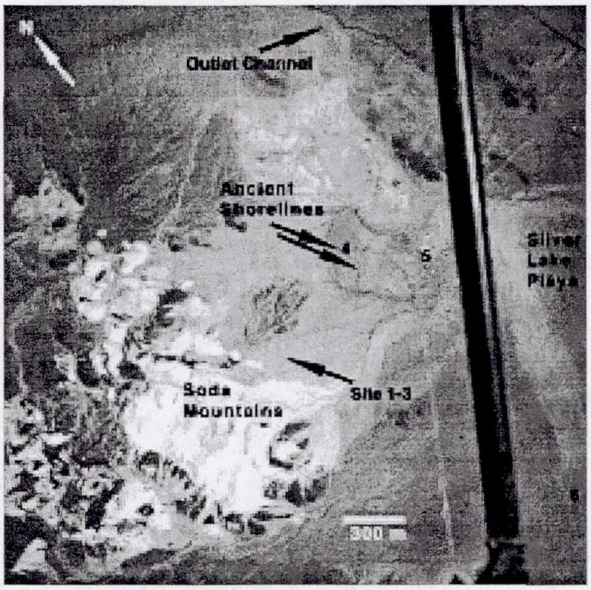

Figure 1. Field site for SL99 test. Sites 1-6 were visited during the mission simulation. Sites 1-3 were on an alluvial fan at the flank of the Soda Mountains. Sites 4-5 were on ancient shorelines of Silver Lake.

Using this payload and mission approach, the science team synergistically interpreted orbital data, descent imaging, rover imaging and infrared spectra, and microscopic imaging of a trench to deduce a consistent and largely correct interpretation of the geology, mineralogy, stratigraphy, and exobiology of the site. Use of imaging combined with infrared spectroscopy allowed distant source outcrops to be correlated with local rock. Different lithologies were distinguished both near the rover and at distances of hundreds of meters or more. Subtle differences such as a contact between dolomite and calcite were identified at a distance of 1/2 km. A biomarker for endolithic microbiota, a plausible life form to find on Mars, was successfully identified. Microscopic imaging of soils extracted from the surface and subsurface allowed the mineralogy and fluvial history of the trench site to be deduced.

Recommendations for Mars Architecture: Conclusions and recommendations derived from the field experiments follow.

1. The scientific productivity of SL99 shows that this payload and mission approach has high science value and would contribute substantially to achieving Mars exploration goals. Thus, the mission payload originally selected for 2001 is scientifically valid and should be flown. Even though the simulation made limited use of mobility (only 40 m were actually traversed by the rover) the science productivity of the payload was considerable. A stationary 2001 lander carrying this payload would do good science.

2. Rover mobility is severely limited by the command strategy, power sources, and navigation approaches formerly in the Surveyor program baseline. Rovers are unlikely to travel more than 10 m in a command cycle in smooth terrain, and significantly less if there are obstacles. Short duration missions (a few months) are thus unlikely to travel more than a few hundred meters and possibly much less. Limited mobility is useful for exploring site diversity, but ideally science is served by mobility on the scale of kilometers. Increasing rover operational range will require improved onboard navigation technology, use of a referenced positioning system (e.g. GPS) for increased traverse accuracy, more frequent commanding, and/or longer-lived missions.

3. Limitations on rover mobility would be less important if accurate landing site targeting could be performed. Improvements in entry, descent, and landing approach to produce targeting uncertainties of 1 km or less should be pursued.

4. Technologies should be developed to enable longer range mobility than rovers can achieve. For example, a ballistic hopper or airplane with take off and landing capability could provide point to point mobility to explore specific features of interest.

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IN SITU NOBLE-GAS BASED CHRONOLOGY ON MARS. T. D. Swindle, Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721-0092. tswindle@u.arizona.edu

Determining radiometric ages *in situ* on another planet's surface has never been done, and there are good reasons to think that it will be extremely difficult [1]. It is certainly hard to imagine that such ages could be measured as precisely as they could be measured on returned samples in state-of-the-art terrestrial laboratories. However, it may be possible, by using simple noble-gas-based chronology techniques, to determine ages on Mars to a precision that is scientifically useful.

This abstract will 1) describe the techniques we envision; 2) give some examples of how such information might be scientifically useful; and 3) describe the system we are developing (under a PIDDP grant), including the requirements in terms of mass, power, volume, and sample selection and preparation.

Techniques: By determining the abundances of major and minor elements in a sample, heating that sample to release noble gases trapped within it, and then analyzing the abundances of the isotopes of the three lightest noble gases (He, Ne, and Ar), two different types of ages can be determined.

Since one of the naturally occurring isotopes of potassium (K) decays to ^{40}Ar, the abundances of potassium and ^{40}Ar can be used to determine a K-Ar age. This gives the time since the sample was last heated enough to release Ar (several hundred degrees C). For terrestrial samples, metamorphism often resets some, but not all, of the minerals within a rock, so the ^{40}Ar-^{39}Ar technique has largely superseded the K-Ar echnique. On Mars, K-Ar ages are likely to date the crystallization of the rock, unless it has experienced a long or unusual impact history. K-Ar ages are likely to be measurable for martian samples ranging in age from a few million years old to the age of the planet.

The other type of age that can be determined is a cosmic-ray-exposure (CRE) age. Bombardment of any rock by cosmic rays will produce a wide variety of nuclei, including those of the noble gases, by "spallation" nuclear reactions. Since the surface of Mars is only partially shielded from cosmic rays, these cosmogenic nuclides will build up in any rock that is within about 1 meter of the surface. If the abundances of the target elements (basically, the major and some minor elements in the rock) and the cosmic-ray-produced noble gases are measured, and the production rate can be calculated, this gives the length of time the sample has been at the surface. If many samples on a surface have the same exposure age, that age probably represents the age of the surface itself. CRE ages are likely to be measurable from about 100,000 years to a few tens of millions of years. These measurements also give the radiation dose that a sample has experienced, which could be valuable information for quarantine considerations.

Examples: We believe the system described below can measure K-Ar and CRE ages with a precision of about 10%. This leads to two questions. First, are there places on Mars where an age with that precision would be scientifically useful? Second, would the ages determined by those techniques be interpretable in terms of martian chronology?

There are at least two types of terrain on Mars where 10% precision ages would be valuable. 1) Although the relative ages of various surfaces have been determined by crater counts, the absolute ages are very poorly known. Various estimates of the ages of some surfaces encompass virtual the entire history of the planet (e.g., the Late Hesperian-Early Amazonian boundary is anywhere from 0.6 to 3.5 Ga [2]). A single set of K-Ar ages from a suitable surface could pin down the entire cratering curve. 2) Determining the ages of the youngest volcanic or fluvial events would be of immense interest, and could be done by determining CRE ages (and, in the case of volcanics, K-Ar ages) from the surface.

A major concern with the K-Ar system is whether trapped martian ^{40}Ar, from either the mantle or the atmosphere, could lead to erroneous ages. As a first test of how meaningful K-Ar ages might be, Table 1 compares K-Ar of martian meteorites with the crystallization ages of those meteorites [3], using data from

Table 1: K-Ar ages of martian meteorites

Meteorite	Crystallization Age (Ga)	K-Ar Age (Ga)	Ref.
ALH84001	4.51(11)	4.1	3
Chassigny	1.34(5)	1.32(7) 1.46(17)	3 6
Nakhla	1.27(1)	1.30(3) 1.1(3) 1.4(3)	7 8 8
Lafayette	1.32(3)	1.36(3)	7
G. Valadares	1.33(1)	1.34	9
Shergotty	0.165(4)	.14-0.40	3
ALH77005	0.178(6)	0-3.6	3
EET79001B	0.173(3)	0-1.9	3
QUE94201*	0.327(10)	0-0.66	3
Y790327	0.212(62)	0-1.9	3
Zagami*	0.177(3)	0.15-0.24	3

Uncertainty in last digit(s) given in parentheses
* Feldspar separate

the literature for the K-Ar ages. In the shergottites, which contain measurable trapped Ar for other isotopes, trapped ^{40}Ar has been corrected for by assuming a trapped $^{40}Ar/^{36}Ar$ ratio of 200-1900, which encompasses likely values for the mantle and atmosphere [4]. For the other meteorites, the listed K-Ar ages are values reported in the literature. The only old sample (ALH84001) gives a K-Ar age slightly (roughly 10%) younger than its crystallization age, presumably reflecting later impacts. Four intermediate-aged samples give K-Ar ages indistinguishable from their crystallization ages. The six youngest samples all have a significant amount of trapped ^{40}Ar. Only two of them give demonstrably non-zero ages. However, these ages, while uncertain to much more than 10% because of the corrections that have to be applied, do agree with the crystallization ages. Hence the meteorites all give ages that either agree with the crystallization ages (to 10% or the uncertainty, whichever is larger), if they give ages at all. Furthermore, it is possible that a large fraction of the trapped argon in the shergottites was implanted by the impact that ejected the meteorites from Mars, so *in situ* measurements might be less affected by trapped Ar.

There should be little doubt that CRE ages could determine the age of a surface. The technique has already been used to determine the ages of young lunar craters in the vicinity of the Apollo landing sites (e.g., Cone, North and South Ray Craters) [5]. CRE ages have also been used for terrestrial surfaces, but in terrestrial applications, larger samples and higher precision measurements are required than will be necessary for Mars, where the cosmic-ray flux is roughly 1000 times higher.

Proposed system: Under a PIDDP grant for which funding has just started, we are developing a system that can determine noble-gas-based ages *in situ* at 10% precision, using components developed through other programs by three different laboratories. The system is summarized in Table 2. Basically, we used Laser-Induced Breakdown Spectroscopy (LIBS) to measure elemental abundances, an oven modified from MPL TEGA to heat the samples, and a miniature quadrupole mass spectrometer array to measure the noble gases. All of the component parts have been developed with spacecraft applications in mind, so all are miniaturized. The ovens will be significantly redesigned from TEGA. Since we do not need to perform calorimetry, but do need higher maximum temperatures, the requirements for that part of the system will change (mass and volume will certainly become smaller, we expect power consumption to remain the same or decrease). Note that the subsystems operate sequentially, so the total power required is the maximum power for any individual subsystem.

The system would determine K-Ar and CRE ages (both could be determined on each sample) on 12 samples of a few milligrams each. It assumes that material will be provided in the form of powder (e.g., from a drill), from within rocks at a site than has been characterized well enough to know where in martian stratigraphy it falls, and whether there are nearby large impact craters that could be affecting ages. Note that the LIBS analysis guarantees a chemical analysis of the sampled rock. Since the ages determined will be much less accurate than what could be done with a returned sample, we suspect that our system will be more valuable on an *in situ* mission than a sample return mission. However, it could provide help in sample selection or radiation verification for a sample return.

Acknowledgments: This work is supported by PIDDP Grant NAG5-9198.

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Table 2: *In situ* geochronology system

Subsystem	**Developer(s)**	**Mass (kg)**	**Power (W)**	**Volume (cm^3)**
Elemental analyzer (LIBS)	D. Cremers, LANL	1.4	2.3	1400
Oven (TEGA)	W. Boynton, LPL	5.7	60	4000
Mass spectrometer (QMSA)	A. Chutjian and M. Darrach, JPL	1.8	12	2150
Total		8.9	60	7150

Other Science Team members: D. Kring (LPL), S. Baldwin (Syracuse)

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NEXT-GENERATION ENTRY/DESCENT/LANDING SYSTEM FOR MARS LANDERS.

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Introduction: Many important scientific objectives for Mars exploration require the ability to land safely at select sites. The "first-generation" entry, descent, and landing (EDL) systems used in previous missions imposed limitations on target site selection due to the delivery accuracy achievable and those systems' inability to recognize and avoid hazardous terrain. This abstract outlines key capabilities of a proposed second-generation EDL system, currently under development by a consortium of NASA centers, industry, and academic institutions.

EDL System Description: An illustration of a representative system concept is provided in Fig. 1 below. The entry capsule pictured is being designed for both direct entry, as has been done in the recent *Mars Pathfinder* and *Mars Polar Lander* missions, or delivery into the atmosphere from orbit, if it is desired to carry the spacecraft into orbit prior to landing. Hence, carrier vehicle options range from a cruise stage to an orbiter spacecraft with a mission of its own.

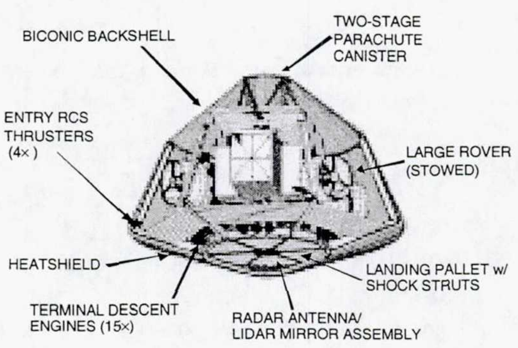

Figure 1: Entry Capsule Cutaway View

The entry capsule is designed to accommodate potentially large (600-1000 kg) payloads while providing aeromaneuvering capability for closed-loop guidance to within ±3 km (3σ) or better of a designated target site. A biconic backshell is used to obtain high volumetric efficiency in payload packaging (a large rover is shown in Fig. 1 as an example). A two-stage parachute system is employed, enabling deceleration of very large spacecraft while allowing time for terminal sensing and hazard avoidance during terminal descent. Both radar and lidar sensors are used for local terrain-relative navigation to identify safe landing sites to the spacecraft's guidance system.

The touchdown event itself is made robust as possible to any residual terrain hazards. Figure 1 shows one example of a robust landing approach; a pallet-type structure augmented with webbed shock struts to help prevent tip-over. This scheme and other alternatives are discussed further by Rivellini.[1]

The architecture of this system is structured not only to incorporate current sensor technology and guidance/navigation logic, but also to readily accommodate future capabilities as warranted. Examples of potential future additions include the capability to perform onboard radio navigation via orbiting spacecraft or surface beacons, and guided parachute descent for "pinpoint" delivery to a designated target site.

EDL Sequence of Events: The key events occurring during entry, descent, and landing are illustrated in Fig. 2. This figure also provides approximate values of the altitude, velocity, and timing of each event for a representative direct entry mission.

Approach Phase (not shown). Prior to entry the spacecraft must be guided to the target entry corridor. The spacecraft's own propulsion system and guidance system are capable of doing so, or the entry capsule may be augmented with an external propulsion system if desired, controlled by the onboard guidance system.

Entry/Atmospheric Deceleration Phase. Once the spacecraft begins to encounter the atmosphere, its entry guidance logic is activated. The guidance system computes bank angle commands to steer the capsule's lift vector such that the correct parachute deploy conditions will be achieved at a desired position relative to the target landing site. This guidance scheme is a derivative of the Apollo entry guidance approach,[2] and has been tested extensively in a high fidelity simulation environment[3] for use at Mars.

Parachute Descent Phase. Deployment of the supersonic parachute is triggered by the entry guidance logic at approximately Mach 2.2. This parachute is a derivative of the *Mars Pathfinder* mortar-deployed parachute, and serves as a drogue parachute in this EDL system, decelerating the spacecraft quickly to subsonic speeds. Once the vehicle reaches Mach 0.8, the backshell and supersonic parachute are jettisoned (eliminating mass that is no longer needed), and a much larger (up to 30 m) subsonic main parachute is deployed. This parachute is designed to quickly bring even large vehicles to low (40-50 m/s) terminal velocities that provide sufficient time for terminal sensing prior to powered descent.

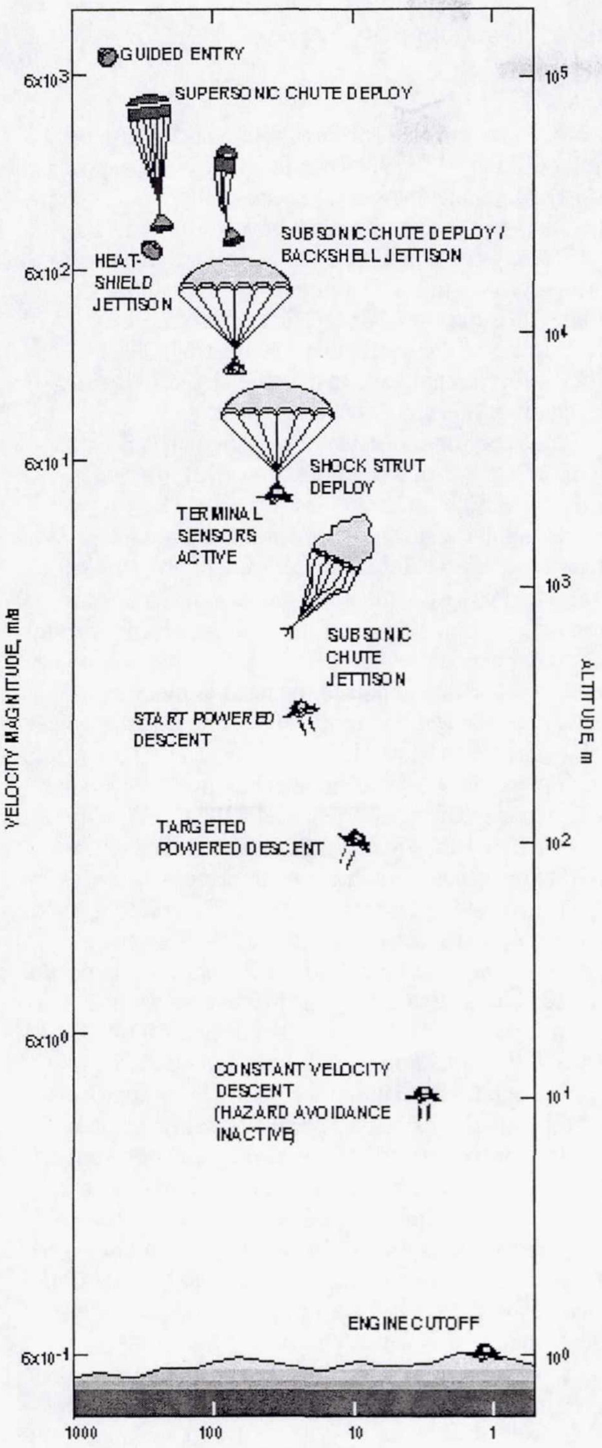

Figure 2: EDL Sequence of Events

During parachute descent terrain-relative navigation is initiated. The landing radar acquires the surface at an altitude of 3700 m, allowing the onboard navigation system to accurately determine the spacecraft's surface-relative altitude and velocity. In the 1500 to 1000 m range a scanning lidar begins periodically generating local elevation maps of the surface, in the area surrounding the guidance system's current projected landing site. The lidar elevation maps are used within the guidance system to identify any potential hazards near the projected site, and to redesignate the target site to a safer location if necessary.

Powered Descent Phase. Once the navigation system and hazard identification logic have designated a safe, and reachable, local target site, the lander's guidance system computes an appropriate time to separate from the subsonic parachute and begin powered descent. This computation establishes a trajectory that will reach the designated target site while maximizing the amount of available performance margin.

The radar and lidar sensors, along with the hazard detection and retargeting logic, continue to operate during powered descent, scrutinizing the target site and the surrounding area as the effective resolution of the lidar-generated terrain maps improves, redesignating the target site as needed. The guidance system periodically computes a new reference trajectory leading to the current target site, using a set of algorithms derived from the powered descent guidance logic for the Apollo Lunar Module.[4]

Touchdown. Powered descent concludes with thrust termination approximately 1 m above the surface, resulting in velocity components at touchdown of approximately 3 m/s (vertical) and a tolerance of ±0.5 m/s (horizontal), well within the capabilities of the landing/arrest approaches under consideration.

Development Plan: Prototype development and test activities for new system components have already been initiated, including a prototype lidar/hazard detection system, subsonic parachute, and aerodynamic implements for hypersonic maneuvering.

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Ensuring radiation safety for Mars-bound astronauts. R. E. Turner ANSER, Suite 800, 1215 Jefferson Davis Hwy, Arlington, VA 22202, (turnerr@anser.org)

Introduction: Human expeditions to Mars will be the most ambitious space missions of our time. To execute these missions successfully, the radiation environment must be understood and risks appropriately managed from a systems perspective [1,2,3]. Mars exploration missions from 2001 through the next twenty years present exciting and unique opportunities for advances in radiation risk management of a future human mission to Mars. A major HEDS objective is to characterize the Martian radiation environment. In addition, the Mars mission cruise phases provide multipoint observations of SPEs in the critical region of the heliosphere (1 to 1.5 AU) needed to reduce the in-flight radiation risk to a future Mars-bound crew. To enable the incorporation of appropriate instrumentation, it is critical that the Mars exploration roadmap continue to recognize the importance of energetic particle detectors and radiation monitors on landers, orbiters, and during the cruise phase.

Physics background: It is generally accepted [4,5] that there are two classes of SPEs, each with distinct signatures and broad characteristics. Impulsive flares may produce particle events that are electron-rich, relatively short-lived (hours), and generally limited to within a 30-degree longitude band about the nominal field line connected to the active region. Gradual particle events by contrast are proton-rich, long-lived (days) and may be spread over a broad range of solar longitudes, in some cases over 180 degrees.

The very large SPEs that pose a risk to astronauts fit in the "Gradual Event" category. They are produced by the shock associated with fast CMEs [6,7,8]. For a fast CME, particle acceleration begins as the shock forms in the solar corona and continues as the shock moves out into the interplanetary medium. Energetic particles immediately stream out along the magnetic field lines to 1 AU. As the shock expands, it crosses other field lines, accelerating particles as it goes, and, within tens of minutes of shock formation, particles are flowing outward over an extremely broad front. Maximum acceleration occurs near the nose of the shock, ahead of the CME, and the intensity falls off around the flanks of the shock. As the structure propagates outward, the successive magnetic field lines that connect an observer with the shock sweeps counterclockwise across the shock's surface, averaging over diverse shock conditions.

Need for additional observations: A complete picture matching the physics of particle acceleration to the detailed observation of any one event is very difficult due to the inherent three dimensional nature of the event, our lack of distributed observations, and the complex nature of the underlying processes occurring near the sun during CME production and within the ambient solar wind [9]. There are many things going on nearly simultaneously, and several of them may either be directly related to the production of large SPEs, or sufficiently correlated to act as proxies to tag an ongoing event as likely to produce a significant SPE. Some SPEs have a secondary peak flux that occurs with the passage of the shock ahead of the CME. There is little observational data on the spatial and temporal variation of this shock-enhanced peak.

The need for correlated observations has been recognized by several workshops convened to examine SPE risk mitigation strategies [eg., 10,11]

Recognizing this need, a workshop established to determine Mars radiation measurement objectives for the Mars 2001 mission recommended surface measurements of radiation exposure, correlated with orbital measurements of the input flux. As a secondary objective the workshop endorsed the need to measure the radiation dose and radiation quality onboard the spacecraft en route to Mars [12].

Surface and orbital measurements: Despite the lack of a significant magnetic field, the thin atmosphere (one percent of the thickness of Earth's atmosphere) may provide adequate shielding to protect the astronauts on the Martian surface from SPE radiation, even under minimal spacesuit thickness. Simonsen, et al., 1990 [13], modeled the dose equivalent from exposure to GCR and SPE at a range of Martian elevations (0 to 12 km). The GCR exposure varied from 10 to 18 cSv, while SPE exposure varied from 10 to 30 cSv. Note that the annual BFO guideline of 50 cSv is approached at high altitudes. Recent investigations, which more carefully incorporated backscattered neutrons, suggest the dose equivalent may be higher than initially estimated [14]. *In situ* radiation monitors, as originally planned for the Mars 2001 mission, must obtain more information about the radiation levels at the Martian surface for a variety of altitudes and a range of subsurface conditions to validate models.

Cruise phase measurements: Through the nine or so months in transit, instrumentation on Mars-bound spacecraft would have the potential to observe multiple solar particle events. The cruise phase of orbiter -lander pairs provide unique opportunities to increase our understanding of the acceleration mechanisms for energetic solar particles by providing multipoint *in situ* measurements of the environment. These measurements can be correlated with near-Earth-based observations of solar activity and particle flux. Detailed interpretations of the data will also consider differences in solar latitude and distance from the Sun.

Ensuring radiation safety for Mars-bound astronauts. R. E. Turner

Potential Instruments: The MARIE instruments on the Mars 2001 lander and orbiter were designed to measure the energetic particle background and the secondary particles generated in the Martian atmosphere and on the Martian surface. The combination of orbiter and lander measurements was to provide particle flux above and below the Mars' atmosphere to validate transport codes to correlate with dose measured by the lander. The orbiter instrument consists of a particle spectrometer that can measure the energy spectra of charged particles over energy range of 15-450 MeV/n. The lander carried a smaller particle telescope, and two proportional counters.

During the cruise phase, the lander and orbiter instruments can be exposed to the interplanetary environment. When not in conflict with cruise phase operations, both instruments can be powered to collect and store data. The data can be time-tagged and relayed to Earth periodically.

It is important that the sensors are sensitive to the energy range of ten to a few hundred MeV and can sustain a count rate of 10^4/s-sr-cm^2. Appropriate instruments can be low mass (less than five kilograms) and low power (a few watts) as demonstrated by NASA's STEREO mission. JPL studies [15] have demonstrated the feasibility of similar instruments in small deep space micromissions with total spacecraft mass of 15 kilograms. Such spacecraft could be elements of secondary of missions of opportunity.

Correlation with Space Physics Missions: Mars missions can be complementary to planned space physics missions, such as Stereo, and proposed Living With a Star missions, particularly the Sentinel mission which is intended to observe CMEs and SPEs over distributed heliolongitudes *inside one AU*. The Mars program provides the opportunity to extend these important measurements *out to 1.5 AU*.

Conclusions: Surface measurements of the Mars radiation environment, correlated with orbital measurements of the incident flux, provide the only way to validate models of radiation exposure for future human missions. Since the surface flux will vary with Martian altitude and with subsurface composition, these measurements are best made at multiple surface locations over varied geography and altitude.

Coordinated launches of two or more spacecraft to Mars during recurring periods of favorable Earth/Mars alignment, along with near-Earth observations of solar activity and particle flux, provide unique opportunities to advance our understanding of SPEs. Multipoint observations of energetic particle flux will provide insight into the acceleration mechanism and the evolution of SPEs. This in turn will support efforts to reduce the risk these events pose to humans in space.

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CCD-based XRD/XRF for Determining Environmental Mineralogy on Mars. D. T. Vaniman[1], D. L. Bish[1], D. F. Blake[2] and S. J. Chipera[1], [1]Los Alamos National Laboratory, Geology and Geochemistry, MS D462, Los Alamos, NM 87545 (vaniman@lanl.gov), [2]NASA Ames Research Center, Mail Stop 239-4, Moffett Field, CA 94035.

The Need for Understanding Environmental Mineralogy on Mars: Health effects from Martian dusts will be a concern for any manned Mars missions. Nuisance dusts plagued the Apollo astronauts [1], but dusts of more hazardous mineralogy, in habitats occupied by Mars astronauts weakened by a long-duration mission, may be more than a nuisance. Chemical hazards in Martian regolith attributable to S, Cl, Br, Cd, and Pb are known or strongly suspected to be present [2], but terrestrial studies of the health effects of dusts indicate that accurate determination of mineralogy is a critical factor in evaluating inhalation hazards [3]. Mineral inhalation hazards such as the Group-1 carcinogenic zeolite erionite, which is demonstrated to cause mesothelioma, cannot be identified by chemical analysis alone. Studies of palagonite analogs raise the possibility that erionite may occur on Mars [4].

In addition to health effects concerns, environmental mineralogy has significant importance in resource extraction, groundwater use, and sustained agriculture. The high sulfur and chlorine content of Martian regolith will affect all of these uses, but the nature of mineralogic reservoirs for S and Cl will determine their uptake and concentration in extracted groundwater and in agricultural applications of regolith. Wet chemistry experiments planned for the Mars Environmental Compatibility Assessment (MECA) will define some of the consequences of water/soil interaction [5], but an understanding of the mineralogic basis for water-rock reactions is needed to understand the mechanisms of reaction and to apply the results of a few experiments to larger scales and different conditions.

Methods for Determining Environmental Mineralogy in Space: The value of chemical data for soil analysis has been proven by the Mars Viking and Pathfinder surface landers. Although the data obtained have been meager, they have provided useful constraints on our current understanding of the Martian surface. However, chemical data alone leave serious gaps in our understanding of a planet such as Mars since a single chemical composition may represent a wide range of mineral assemblages and complex minerals may form in combination with H, S, and halogens. The mineralogy, which is much more critical to planetary surface science than simple chemical composition, will remain unknown or will at best be imprecisely constrained unless the minerals present can be identified unambiguously.

Diffraction is the technique of choice for mineralogical analysis in terrestrial laboratories. X-ray diffraction (XRD) is a direct and accurate analytical method for determining mineral species; data obtained by XRD are fundamentally linked to crystal structure, the basic factor in determining a mineral identification. We have developed laboratory XRD methods that recognize occurrences of hazardous minerals such as erionite in abundances well below 500 ppm [6].

Most of the ambiguous mineral identifications obtained with remote spectral sensing (*e.g.*, visible and IR spectra) can be resolved by XRD. Additional chemical data, obtained by XRF, can greatly improve the interpretation of complex samples. Several concepts for combined XRD/XRF have been proposed in the past decade, using a variety of configurations. The concept we summarize here is based on the CHEMIN instrument, which uses a single CCD detector for both XRD and XRF analysis. A detailed description of the prototype CHEMIN instrument is provided in [7]; that reference emphasizes the use of CHEMIN in Martian exobiology studies but the basic concept is applicable to a wide range of mineralogic investigations.

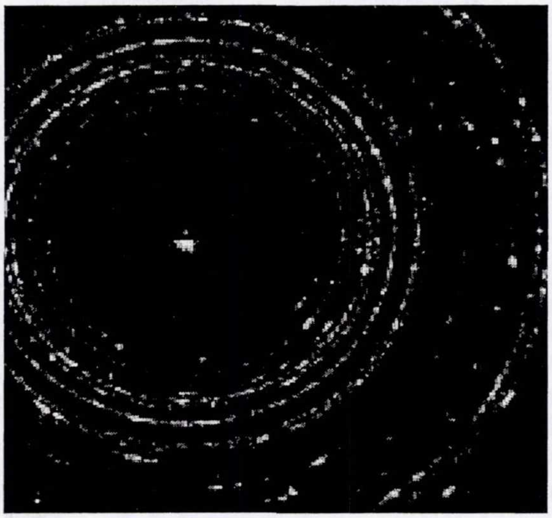
CCD-based XRD/XRF Instrumentation for Environmental Mineralogy: The traditional and well-tested method of definitive mineral identification by XRD has not been used on any planetary surface other than Earth. CHEMIN, which was developed to address this deficiency, uses transmission geometry and a CCD detector in single-photon counting mode to discriminate between diffracted and fluoresced X-rays on the basis of energy. The CCD detector in the current design is 1 cm^2 and could be incorporated in an instrument of ~500 cm^3, weighing <1 kg and operated at ~2 W [7].

Conventional laboratory methods for XRF and XRD analysis use fine powders or fused samples (for XRF). Production of such samples is labor intensive and would be difficult to automate for remote applications. However, appropriately designed robotic XRD/XRF systems can be optimized to handle poorly powdered samples. This is particularly important in XRD analysis, where "spotty" diffraction patterns from poorly prepared or natural powders (*i.e.,* poor particle statistics) present problems in most conventional diffraction configurations. The CHEMIN CCD configuration is designed to measure entire Laue diffraction rings below ~35° 2θ, thereby compensating for poor powder preparation, such as might be produced by robotic sampling systems. The spotty Laue

rings are not a problem in the CHEMIN configuration because the system collects ~100 times the data used in conventional detector systems. Circumferential integration removes much of the uncertainty introduced by spotty diffraction rings, and the quality of the Laue rings provides information about grain size (spottiness diminishes markedly at grain sizes <10 μm and rings become smooth as grain size diminishes to ~5 μm).

Figure 1 shows a CHEMIN diffraction pattern for poorly powdered celestite ($SrSO_4$), one of many members in the complex family of ~1750 S-bearing minerals, several of which could be present in Martian rocks or regolith. Although visibly spotty, integration of the Laue rings on this pattern produces a plot of diffracted intensity versus 2θ that can be used easily with advanced data reduction techniques such as the Rietveld method. We have tested CHEMIN with many pure minerals and mineral mixtures to examine its potential in mineralogic exploration of extraterrestrial bodies. Rietveld refinement methods were applied to XRD data to provide unit-cell parameters and quantitative phase information from ~1-mg sized samples. Good refinements were obtained with pure minerals or simple mineral mixtures, and trace calcite (1.6%) and quartz (0.2%) were readily identified in an aragonite sample. Because of limited diffraction resolution, results were poorer with complex mixtures such as basalt, although refinements yielded reasonable results. This limitation can be overcome if a CCD with more pixels than the prototype CCD (512x512) is used. In addition, CHEMIN analyzes a very small amount of powder, which illustrates the advantageous sensitivity of the CCD detector, although this feature may limit accuracy with some samples due to sample statistics (*i.e.*, too few grains analyzed). Small sample size, however, will not be a problem where fine-grained regolith or eolian samples are analyzed and particularly where the respirable size fraction (≤10 μm) is of principal concern.

Sampling of Martian Regolith: Natural powders and dusts occur on most planetary surfaces, including Mars. The optimum crystallite size for XRD of minerals with Cu Kα radiation is on the order of 1-10 μm and sizes up to ~100 μm are often suitable. Mars Pathfinder experiments point to the existence of at least some soils of <40-μm grain size [8] and eolian accumulations on spacecraft surfaces had grain sizes of <2 μm with compositions representative of the bulk soil [9]. Both materials are important targets for analysis; eolian deposits carry information that can be used to infer regional compositions far beyond the range of a rover, and analyses of soils provide information on weathering processes. In addition, both soils and eolian dusts must be considered in terms of inhalation hazards, impact on Mars-base environmental systems, and resource utilization.



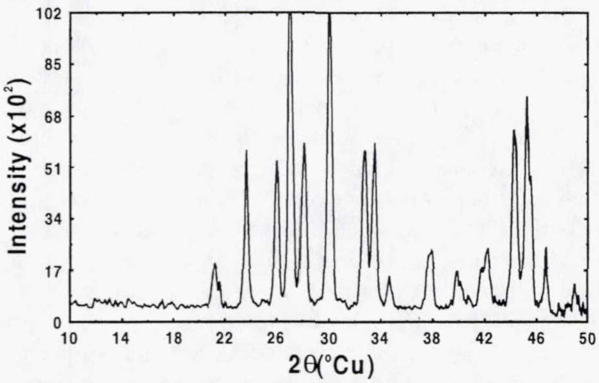


Figure 1. CHEMIN diffraction pattern of poorly powdered celestite, showing the spotty diffraction rings from large crystallites in the sample, and the smooth pattern of intensity versus 2θ obtained by circumferential integration of the diffraction rings.

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POTENTIAL ATMOSPHERIC AND BIOMARKER MEASUREMENTS ACQUIRED BY *IN SITU* INSTRUMENTATION ON MARS J. H. Waite[1], D. S. Bass[1], D. T. Young[2], and G. P. Miller[1] [1]Southwest Research Institute (P.O. Drawer 28510 San Antonio, TX 79228-0510 hunter@kronos.space.swri.edu), [2]University of Michigan (Space Physics Research Laboratory, 2455 Hayward Street, Ann Arbor, MI 48109-2143 dtyoung@umich.edu).

The use of *in situ* measurements on the Martian surface: 1) can greatly improve our ability to select sample return materials with high scientific potential and 2) can be used to study the climate history of Mars. In this paper we discuss the principals of sample preparation, gas chromatography, mass spectrometry, and related techniques that can achieve the measurement objectives described in a companion abstract. Here we also discuss an investigation we have undertaken in coupling of a mass spectrometer to a differential scanning calorimeter such as that developed by the University of Arizona for the Mars Polar Lander MVACS payload.

Atmospheric Measurements. The detection of compounds in the parts-per-billion (ppb) to parts-per-quadrillion (ppq) level is a considerable technical challenge even for the most sensitive of instrumental techniques currently available. In light of the severe resource constraints imposed on lander instruments we have concluded that pre-concentration of the evolved gas prior to its introduction into the mass spectrometer presents the most practical method to achieve the enhancement in sensitivity necessary for accurate chemical characterization of evolved compounds.

The gas sampling and concentration system for organic and inorganic volatile species is based on a proven design for adsorption of these gases here on Earth. It will create a concentrated water sample in order to obtain minor species and oxygen abundances by using an adsorbent with H_2O selective properties. Several additional adsorbents for organic and inorganic volatile compounds will also be employed. The sorbent materials are reversible upon heating so that sampling and measurement can be repeated using a single concentration device.

The gas sampling system is coupled to a high-sensitivity electron bombardment ion source and either a time-of-flight mass spectrometer or a magnetic deflection cycloidal mass spectrometer, depending on resource constraints

Surface/Subsurface Measurements We have undertaken a study to investigate a low power, low mass integrated prototype soil analyzer capable of performing thermal gas analysis. The instrument package will be capable of accurately determining the thermal phases of volatiles, minerals, and the chemical composition of their evolved gases. It is comprised of a soil processor, differential scanning calorimeter, a tunable diode laser spectroscopy system, and a mass spectrometer. We are prototyping the coupling of the UA thermal and evolved gas analyzer to several different mass spectrometry designs, including a time-of-flight (TOF) mass spectrometer and a cycloidal mass spectrometer.

Organic Biomarker Measurements Extraction techniques for a large number of organic molecules bound in soil or in a rock matrix are well developed. The analysis of soil and rock cores for specific biomarkers is used by the oil industry to help identify potentially oil rich deposits. The general technique involves the extraction, cleanup, concentration followed by analysis. Extraction techniques make use of slightly polar organic and sometimes inorganic solvent systems such as supercritical CO_2 with a polar organic modifier such as methanol. The efficiency of extraction is generally better than 80% for most compounds. The most difficult step in the process is the cleanup of unwanted interferant compounds that are coextracted in the extraction step of the process. This generally requires passing the sample at low pressure through columns packed or coated with adsobents that will selectively retain the interferant compounds allowing the compound of interest to pass through the device, recovered and concentrated for analysis.

There has been widespread interest in recent years to develop extraction and isolation techniques using microfluidic MEMS devices to deliver reagents to extract, cleanup and separate components of interest by use of on-line microdialysis [1]. These postage stamp sized microfluidic "laboratory on a chip" devices require microliter volumes of reagents, can easily be interfaced to mass spectrometers, are sufficiently small that several devices can be integrated onto a single package for redundancy and can deliver a concentrated sample using small volumes. The use of microfluidics in combination with capillary electrophoresis has allowed post column derivitization of chromophores to improve detection by UV/VIS for compounds that do not have functional groups that absorb at these wavelengths. Techniques have also been developed for the addition of reagents that

promote electrospray ionization of organic compounds followed by mass spectral analysis.

The incorporation of microfluidic MEMS devices used for the extraction, cleanupand concentration of biomarkers and other organic compounds of interest appears to be a promising approach to follow considering the limited resources available on landers. The analysis of these compounds by mass spectrometry after extraction and cleanup from the sample matrix can be performed by a variety hyphenated techniques that include but not limited to GC/MS, Matrix Assisted Laser Desorption Ionization (MALDI), Secondary Ion Mass Spe trometry (SIMS) and Plasma Desorption Mass Spectrometry (PDMS). MALDI is a soft ionization laser desorption technique with minimum fragmentation of the parent ion that can be performed utilizing a low power laser (diode laser). The technique involves the mixing of the extract with a organic compound that has high absobance efficiency for the laser radiation. This results in the ionization of the compound from a surface after a short duration laser pulse is focused which is ideal for time-of-flight mass spectrometers whose extraction pulse can be synchronized with the laser pulse. In SIMS, a primary gun of neutral or charged atoms such as argon or xenon is focused on a surface containing the analyte. The primary beam ablates the matrix containing the analyte ionizing the analyte in the process into the mass spectrometer for analysis.

Plasma desorption mass spectrometry utilizes a radioisotope such as Californium that undergoes spontaneous fission. The fission-fragment induced ionization is highly efficient soft ionization that preserves molecular weight info rmation and since the ionization occurs from a plane (all ions having nearly identical starting times) is ideal for high resolution time-of-flight mass spectrometry.

Both subsurface and atmospheric detection of methane gas is also of general interest. The low molecular weight of methane combined with its low abundance presents similar problems as do the noble gases for enrichment. The use of graphitized carbon blacks coated on molecular sieve materials are useful for trapping this compound. Soil samples can be heated and the effluent directed to a small trap containing this material for enrichment. Air samples can be obtained by pumping a volume of atmosphere through the trap. Methane can then be thermally desorbed onto the head of a gas chromatography column for separation from other gases also trapped and analyzed by mass spectrometry or a thermal conductivity detector

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The Athena Raman Spectrometer Alian Wang[1], Larry. A. Haskin[1], Bradley Jolliff[1], Tom Wdowiak[2], David Agresti[2], Arthur L. Lane[3], and the Athena Science Team. [1]Washington University, Dept. Earth & Planetary Sciences, St. Louis, MO, 63130, [2]University of Alabama at Birmingham, Dept. Physics, Birmingham, AL, 35294, [3]Jet Propulsion Laboratory, Pasadena, CA, 91109

Introduction: Raman spectroscopy provides a powerful tool for *in situ* mineralogy, petrology, and detection of water and carbon [1,2,4,5,]. The Athena Raman spectrometer is a microbeam instrument intended for close-up analyses of targets (rock or soils) selected by the Athena Pancam and Mini-TES. It will take 100 Raman spectra along a linear traverse of ~1 cm (point-counting procedure) in one to four hours during the Mars' night. From these spectra, the following information about the target will extracted: the identities of major, minor, and trace mineral phases, organic species (e.g., PAH or kerogen-like polymers), reduced inorganic carbon, and water-bearing phases; chemical features (e.g. Mg/Fe ratio) of major minerals [6]; rock textural features (e.g., mineral clusters, amygdular filling and veins). Part of the Athena payload, the miniaturized Raman spectrometer has been under development in a highly interactive collaboration of a science team at Washington University and the University of Alabama at Birmingham, and an engineering team at the Jet Propulsion Laboratory. The development has completed the brassboard stage and has produced the design for the engineering model.

Instrument characteristics The miniaturized Raman spectrometer consists mainly of two parts: a probe deployed by a robotic arm, and a source-spectrograph unit consisting of the laser, detector, electronics, and microprocessor, all located within the warm electronic box of the rover. The excitation laser beam and collected Raman signal are transmitted via optical fibers. The Raman probe has a scanning mechanism to enable linear traverses. The 532 nm line of a diode-pumped solid state laser is used as the excitation source. The laser delivers a condensed, ~10 mW beam (~25μm in diameter) onto the sample. The spectrograph covers two spectral regions: 200-1700 cm^{-1} (for oxides, oxyanions, and carbonaceous materials) and 2500-4000 cm^{-1} (for hydrogen bonded to O, C, N, S). It has a spectral resolution of 6-7 cm^{-1} and a peak position accuracy of ~1cm^{-1}. A point-counting measurement procedure was designed to take spectra from original surfaces of rocks or soils and from the distal ends of samples obtained by coring. As the target surface will be uneven, the sampling objective has an 8 mm working distance. The instrument needs no auto-focusing mechanism, because the optical design [3] enables a depth-of-sampling range for strong Raman scatters of ≥2.5 mm. The total mass of the system is ~2.5 kg, of which the probe is ~220 g. A maximum of 36 Watt-hours is required per set of 100 Raman spectra. The size of the brassboard is ~5.5 × 7.5 × 7.7 cm for the probe, and ~16.4 × 15.9 × 7.7 cm for the spectrograph.

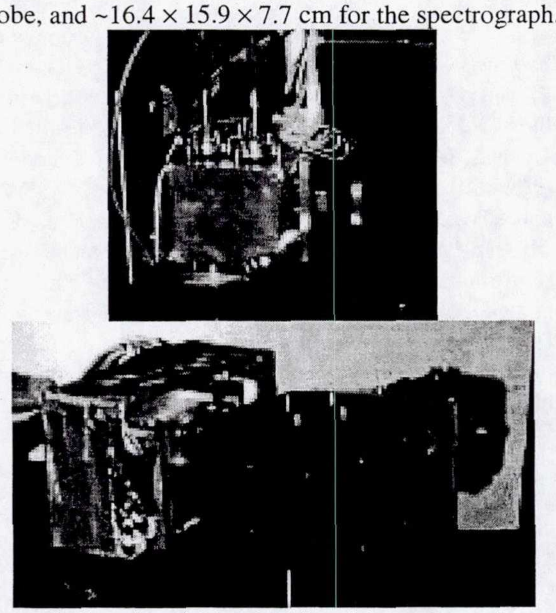

Figure 1. Brassboard 1d probe (above) & spectrograph.

Brassboard models performances: Extensive performance tests have been done on all breadboard and brassboard models. Overall, they have proved highly successful, demonstrating that a Raman spectrometer can be built that is suitably miniaturized and low enough in power for use as an on-surface planetary instrument, yet retains high detection sensitivity and yields laboratory quality spectral resolution over a broad wavelength range. These features are essential to provide accurate mineral characterization.

Raman spectra obtained by using brassboard 1b on three common igneous minerals are shown in Fig. 2. Reduced carbon of probable organic origin is readily identified from the spectra of two ancient cherts (Fig. 3). The detection of carbonate and sulfate minerals is especially important, since they are potentially important indicators of ancient Mars environments and evidence of past water activity. Raman spectra of some natural carbonate and sulfate minerals obtained using brassboard 1d appear in Fig. 4. These spectra demonstrate that mineral classification (i.e., silicate, carbonates, sulfates) can often be achieved by mere inspection of raw spectra, and that chemical features of individual mineral species are revealed by detailed Raman parameters such as peak positions.

The Athena Raman Spectrometer: L. A. Haskin, Alian Wang, B. L. Jolliff, T. Wdowiak, D. Agresti, and A. L. Lane

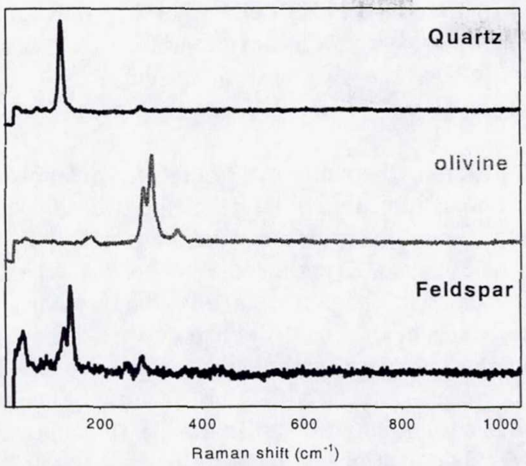

Figure 2. Raman spectra obtained by brassboard 1b from common igneous minerals

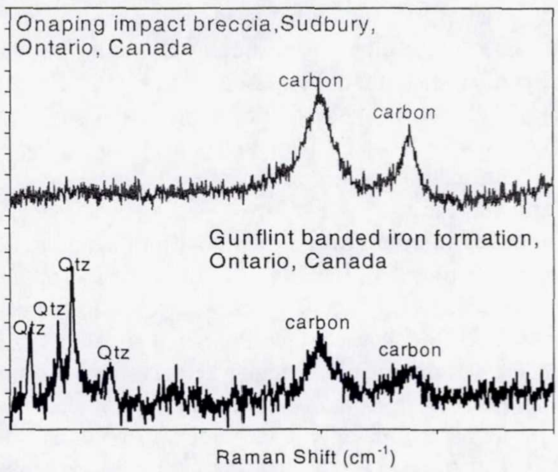

Figure 3. *Raman spectra obtained by brassboard 1b from two ancient cherts*

The sensitivity of the brassboard 1d model was tested briefly at low laser power and untweaked alignment by a 20-point traverse across the surface of a terrestrial basalt. Figure 5 shows three of the Raman spectra obtained. Of 20 spectra taken from this random sampling, 15 yielded identifiable peaks. Further detailed tests of the brassboard are planned.

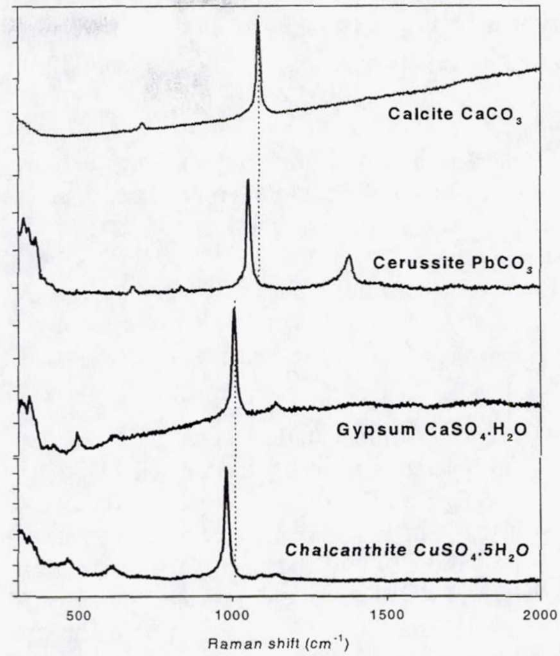

Figure 4. Raw Raman spectra obtained by brassboard 1d from natural carbonate and sulfate minerals

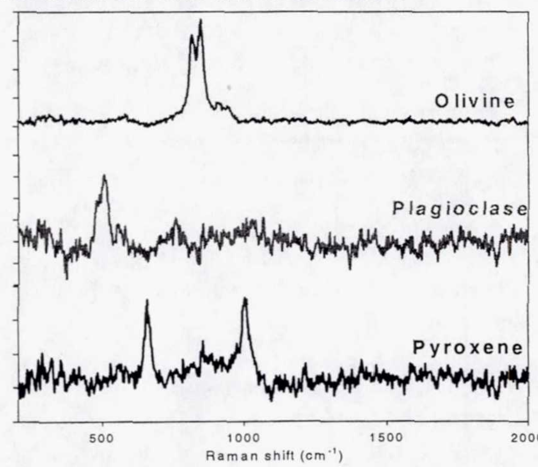

Figure 5. Raman spectra obtained by using brassboard 1d from a volcanic rock sample.

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IN-SITU INSTRUMENTATION FOR EXOBIOLOGICAL OBJECTIVES ON MARS: DEVICES, PROTOCOLS AND STRATEGIES. T. J. Wdowiak, Astro and Solar System Physics Program, Department of Physics, University of Alabama at Birmingham, Birmingham, AL 35294-1170 <wdowiak@uab.edu>.

Introduction: The "life" issue is the most provocative driver for the exploration of Mars, therefore several dicta are necessary. These are:

- Prior to specific "life search" activities it is imperative that understanding Mars as a planet, particularly its ancient nature, is a first condition.
- Proper instrumentation for serving exobiological objectives must be first capable of producing high level planetary science. Highly specialized instruments must be avoided, particularly those of the "test strip" variety. The mistake of the "life search" instrumentation package of the Viking missions must not be repeated
- Instrumentation that elucidates molecular structure is highly suited for both high level planetary science and exobiology objectives
- The most desirable architecture is one that organizes several instruments into an integrated suite to maximize tasking - create "an orchestra"
- The NASA SP-530 "An Exobiological Strategy for Mars Exploration" remains an excellent basis for planning

For the past decade the Astro and Solar System Physics Program of the University of Alabama at Birmingham (UAB) has been engaged in the definition and development of planetary surface instruments directed toward exobiological objectives. Experience with the miniaturization of both Mössbauer and Raman spectrometers, developing an impact tool that is the equivalent of a geologist's rock hammer for robotic obtaining of fresh surfaces, and currently addressing how to do time-of-flight mass spectroscopy on Europa has resulted in a perspective that is, for the most part, one of undertaking instrumentation development to meet scientific objectives rather than tailoring prior interests to "fit in". Since May 1997 considerable effort has been expended in the development of the Athena Raman Spectrometer which is a joint project of Washington University, UAB, and JPL.

Available Instruments: Currently a number of specific instruments have already been developed in conjunction with the Mars Polar Lander and the '01 Athena Precursor Experiment/'03 Athena Rover effort. These exist in the forms of advanced breadboards, engineering models, and flight hardware. Given the expense, and more importantly the time invested, it would seem to make good sense to utilize this now-available technology at least in the '05-'07 launch time frame. The instruments have sufficient compatibility, particularly the Athena items, to be arrangeable into integrated instrumentation suites where performance characteristics overlap and importantly permit in-situ verification of results. In particular it should be understood that the Athena Raman Spectrometer, a near-ready development at the engineering model stage, is the first available instrument that permits unambiguous identification of mineralogy and carbonaceous materials at the microscale level (~25 micron), which is incredibly important for understanding the nature of a composite material, namely a rock! As a molecular structure directed probe, it is fully capable for detection of H_2O and hydroxyl components in all forms. From the standpoint of planetary science it does both the analysis of igneous, sedimentary, and metamorphic minerals as not only stand-alone species, but on the level of microcrystals in rocks. Should carbonaceous inclusions exist in a sample, the microscale capability permits detection at very low whole rock concentrations. It is quite likely that carbonaceous material, if present will be as inclusions rather than being dispersed. This capability, and the current state of development, makes the Athena Raman Spectrometer an ideal instrument of choice for both in-situ exploration and selection of samples for transport to Earth. In the '05-'07 launch time frame it makes sense to consider any instrument suite delivered to Mars to be in the category of a "facility" system available to a community of participants selected through the peer review process.

Desirable Instruments: When looking beyond the '05-'07 launch time frame two requirements come immediately to mind: 1) capability for interrogating samples extracted from subsurface depths and the interiors of rock masses (outcrops or large pieces of ejecta); and 2) isotope abundance determination. Both of these are formidable objectives given the economics of transport of systems likely to be more mas-

sive and energy consumptive than the "couple of kilograms and a few watts" that is the present realistic constraint. It should be pointed out that a "lunar drill" although contemplated, was never taken to the Moon even though the LEM vehicle was considerably larger than what will be available for Mars. The best alternative to a "Mars drill" is to seek out specific pieces of ejecta that can be traced back to a specific crater and utilize smaller core extraction systems to obtain interior samples. Of course shock metamorphism will be an issue; however, lessons of terrestrial impacts ought to be applicable in the interpretative process. Integration of the terrestrial impact research community into Mars exploration will be important.

The isotope abundance determination issue is going to be largely dependent upon developing laser technology that permits conversion of console-size mass spectrometers to miniature flight instruments. Also other means of isotope determination such as plasma spectroscopy need to be explored. This kind of effort could draw upon heritage of uranium isotope separation technology developed over the past three decades and based upon tunable lasers. The optogalvanic effect is a possible detection technique. Cavity-ring down spectroscopy makes possible the spectroscopic detection of very sparse species including hydrocarbons, but again we are looking at a 10-year time frame to achieve a flight instrument.

Recommendation: Save money by utilizing the instruments already "in the pipeline" for at least the '05 and '07 time frame, and invest in the development of new miniaturized instrument technologies for use in the second decade of this century. Also be prepared to accept new technology advances that will come from the non-space community. Remember Raman spectroscopy as an in-situ flight technique wasn't feasible until ~1995.

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Life on Mars: What and Where?

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The search for life on Mars has gathered momentum since McKay et al's [1] publication concerning possible life in a martian meteorite. In this contribution, I present my opinion of what to look for and where based on my own studies of fossil bacteria in the context of the early history of life on Earth. My premise is that the search for extraterrestrial life needs to take place within a planetary context. I first analyse what is known about the context for the origin of life on Earth and what we understand about the first fossil organisms. Then I will briefly compare the early terrestrial environment to that of Mars. Finally I will consider what to look for in the search for life on Mars, and likely environmental locations.

Early Earth

Evidence from basalts from almost the entire history of the Earth indicates that the mantle was oxidised (at least back to Isua times, ca. 3.8 b.y. [2] and possibly back as far as 4.3 b.y. [3]). This implies recycling of hydrated crust which, in turn, implies the presence of surficial water, such as oceans, as well as a tectonic recycling mechanism, such as plate tectonics. Some of the volatiles (water as well as organics) may have come from cometary and asteroid input [4]. The pre-4.3 b.y.-old mantle was essentially dry. Early recycling and melting of crust to produce at least some sialic differentiation is demonstrated by the existence of the Acasta Gneisses (4.1-4.0 b.y.-old) which, themselves, are derived from both hydrated, depleted mafics as well as earlier granitoids [5]. The oxidated state of the mantle precluded the emission of reducing gases from about 4.3 b.y., producing instead CO_2 and water vapour [4]. Despite the lower luminosity of the sun [6], the mainly CO_2 atmosphere would have created an offsetting greenhouse effect [7,8], thus, ensuring temperatures sufficiently high for water to remain liquid at the surface. Partial pressures of CO_2 in the early atmosphere would have put constraints on the pH of the early ocean. Walker [7] calculates that the pCO_2 of the very early atmosphere could have been as high as 10 bars; according to Grotzinger and Kasting [9] pCO_2 could not have been below 0.03 bars otherwise the oceans would have frozen over. Higher pCO_2 results in an ocean with a low pH. Such an ocean would have been more aggressively weathering of the basaltic rocks. Furthermore, lack of O_2 in the atmosphere would have lead to high UV levels at the Earth's surface [10]. Decay of radiogenic nucleides is postulated to have created high heat flow in the early mantle [11], for which the Mg-rich komatiite lavas of the early Archaean are believed to provide some evidence [12] (although another theory postulates komatiite formation from a wetter, cooler mantle [13]).

Owing to the paucity of early Archaean rocks and their generally poor state of preservation, it is not clear to what extent the early Archaean volcanic and sedimentary supracrustal sequences were deposited upon granitoid crust. The majority of the greenstone belts appear to have been formed on (thickened?) oceanic crust [13-15], although the oldest part of the Pilbara craton seems to have been deposited on eroded continental crust [16]. The early crust was formed of small units, unlike the later platform-type continental areas which emerged later on in the history of the Earth [14,17]. A major consequence of the lack of platform areas was the lack of the large-scale carbonate deposits so characteristic of the Proterozoic era. Carbonates in the early Archaean are few and far between: primary deposits are mostly associated with evaporite sequences [9] whereas many of the so-called deep water deposits are actually the result of carbonate metasomatism [18]. Sedimentary deposits consisted of volcaniclastics, mass wasting products and chemical precipitates (especially silica, evaporites and BIFs) [14, 15, 19], deposited in a variety of environmental settings ranging from deep water turbidites, through shallow water, deltaic to alluvial settings. Strong hydrothermal activity was associated with the volcanism and gave rise to strong metasomatism as well as primary hydrothermal deposits [20,21]. On top of this scenario for the early Earth was the late heavy bombardment of the Earth and the Moon which terminated at about 3.8 b.y. One theory has this period lasting from about 4.2-3.8 b.y [22] whilst another proposed a spike in bombardment between 4.0-3.9 b.y. [23]. It hypothesised that some of the impacts could have been of such a cataclismic nature as to completely sterilise the Earth [24].

Early Life

The oldest circumstantial evidence for life (isotopic) indicates that it was well-developed and flourishing by >3.8 b.y. [25]. This means that it survived the period of heavy bombardment, UV radiation, heat, relatively acidic pHs etc. Current theories favour a hydrothermal origin of life based on 16sRNA sequencing [26-28] although there is an alternative "cold start" theory [29]. Or possibly life took refuge in vents during heavy bombardment, thus skewing the record. The oldest morphological evidence for life comes from silicified body fossils (filamentous, coccoid and rod-shaped bacteria [30-32]) as well as their associated biofilms [33,34]. All fossils found to date occur in shallow water to tidal sediments. It is possible that they occur in other environments, such as hydrothermal vents [35] or deeper water sediments such as the alteration rinds of pillow basalts. Relevant studies are underway to determine their environmental distribution.

Apart from their simplicity, one of the key characteristics of these fossils is that they are preserved by silicification (with varying degrees of organic preservation [34]). None of the fossils have been calcified. $CaCO_3$ is

not a good preserver of fossils, partly because of its coarse crystal lattice relative to silica (very fine detail can be preserved with silica [36], and partly because of its susceptibility to recrystallisation and dissolution.

Early Mars

There is a general concensus that early Mars was similar to early Earth, but exactly how similar were they? The recent observation of magnetic lineations in the ancient crust of Mars [37, 38] suggests that Mars may have been tectonically active although its dynamo appears to become extinct by about 4 b.y. The dry mantle, however, indicates that there was little if any overturning of hydrated crust. Indications for water activity are strong on the older surfaces of the planet [39] but weaker on post Noachian surfaces [40]. The early CO2 atmosphere could still have been as high as 0.5-1 bar by the end of heavy bombardment [41]. Such pressures would indicate lower pH in the hydrosphere. By analogy with the Earth, the lack of continental platforms would probably preclude the existence of large carbonate deposits (carbonates therefore will not contribute to the loss of the CO2 atmosphere which was more likely due to impact erosion and sputtering [42]). The active surficial hydrosphere disappeared towards the end of the period of heavy bombardment since when most of the water appears to be stored in a subsurface crysosphere [43]. Volcanism, on the other hand, has always been present [44,45] and could melt the cryosphere. With the same indigenous and exogenous volatile input, liquid water, and sources of energy as the Earth, life could have started on Mars, becoming extinct at the surface as the hydrosphere disappeared [46]. However, life would not have had the chance to develop beyond the prokaryote stage. If it is extant, it may still be found in a dormant stage in the cryosphere.

What and Where?

Mars could still retain vestiges of the prebiotic stage of life which has been obliterated on Earth. We need to understand how that prebiotic stage can manifest itself (in terms of chemical and morphological fossils). I would therefore look for both prebiotic and simple biogenic structures (similar to bacteria and biofilms), containing organic matter or replaced by a mineral. I would especially search for silicified fossils (by comparison with the early Earth, they should be abundant if there was life on Mars). Oxidants at the surface may obliterate chemical fossil biomarkers but silicified biogenic (or prebiotic) structures could still conserve some characteristic signature [47]. Subsurface samples may contain this biochemical fossils. With impact gardening, potential fossils in older formations could be both strewn around the surface as well as pulverised or shock metamorphosed. We need to be able to identify shocked fossils (organic and minerally replaced). There are manifestations of early life on Earth in all ancient, water-associated rocks that have not been heavily metamorphosed, *i.e.* it appears to have been widely distributed from the earliest Archaean. Could the same be true for Mars? In that case we could find potential fossils from shallow water, hydrothermal deposits, evaporite deposits, on pillow basalt surfaces, in cracks in igneous and metamorphic rocks in almost any location, spread by impact. The large deposits of coarse grained hematite [48] prompted excited comparisons with terrestrial BIFs (which have some biogenic component) but they may have been compromised by metamorphism [49] and, therefore, unsuitable as fossiliferous locations.

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RAPID ELEMENTAL ANALYSIS AT STAND-OFF DISTANCES USING THE LIBS CONCEPT FROM THE MARS INSTRUMENT DEVELOPMENT PROGRAM. R. C. Wiens, D. A. Cremers, M. Ferris, and J. D. Blacic, Los Alamos National Laboratory (MS D-466, Los Alamos, NM, 87545, rwiens@lanl.gov).

Introduction: The elemental composition of rocks and soils is one of the most fundamental types of information needed to understand geologic contexts and to search for likely locations of biological activity. Nearly all methods for determining elemental composition involve in-situ analysis, requiring time-consuming maneuvering of a rover to acquire the desired sample. By contrast, analyses at stand-off distances allow nearly a ten-fold increase in the number of samples obtainable over in-situ techniques [1]. Additionally, methods such as APXS have difficulty distinguishing between the pristine sample and rock coatings of either dust or weathering products [2].

Under the auspices of the Mars Instrument Development Program, we have built and are testing a prototype LIBS (Laser-Induced Breakdown Spectroscopy) instrument which can rapidly determine elemental compositions at a distance. Additionally, by depth profiling μm to mm into the sample, LIBS can distinguish between dust or weathering products and the pristine sample. Here we summarize the LIBS concept, describe the initial performance of our prototype, including work at the combined rover tests in Nevada, and summarize potential LIBS contributions to the Mars exploration program.

The LIBS Concept: In the LIBS method [3], powerful laser pulses are focused on the target sample to form a laser spark or plasma. Material within the spark is the result of vaporization/atomization of a small amount of target material. The spark light contains the emission spectra of the elements within the plasma. Collection of the plasma light, followed by spectral dispersion and detection, permit identification of the elements via their unique spectral signatures. When calibrated, concentrations can be determined. Advantages of the method compared to more conventional elemental analysis methods include: (1) rapid analysis (one measurement/pulse); (2) simultaneous multi-element detection; (3) ability to detect all elements (high and low z); (4) ability to clean dust or weathering layers off of sample surfaces; and (5) stand-off analysis capability [4]. Stand-off analysis is possible because the laser pulses can be focused at a distance to generate the laser sparks on a solid. The distance that can be achieved depends on characteristics of the laser and the optics used to focus the pulses on the target.

Recent LIBS Results: We have recently shown [5,6] using a laboratory instrument that a) semi-quantitative results (e.g., 10-20% accuracy) can be obtained for nearly all elements at stand-off distances of up to 20 m. using a compact laser and a 4" objective lens and detector, b) detection limits for nearly all elements at these distances are in the range of 10 to several hundred ppm, c) LIBS works well at all atmospheric pressures from 1 bar to vacuum, with a maximum efficiency between 10 and 100 Torr, and d) the target mass ablated per laser pulse increases with decreasing atmospheric pressure.

The capability to remove surface material from a sample is important, as all Mars rock observations to date appear to be contaminated with dust [2]. In one recent test, layers of sea sand 1, 2, and 3 mm thick overlying a rock sample were removed in 4, 14, and 28 laser pulses, respectively, under Martian conditions (5 Torr CO_2 atmosphere) [5]. Typical excavation rates for the ~1 mm dia laser-produced craters in basalt are much lower, at ~1 μm/shot, but still sufficient to remove weathering layers with repeated pulses.

Prototype Design and Testing: A relatively simple prototype instrument was produced over the last year. As shown in Fig 1, it consists of two sections: 1) the sensor head, including the laser, variable focus beam expander with a 2" diameter objective lens, beam splitter, and a fiber optic couple for receiving the return signal. 2) The body-mounted portion consists of the spectrograph and detector, and the laser controller. Commercial off-the-shelf (COTS) components were used throughout, so weight, instrument volume, power consumption, and some of the optical parameters were not optimized. The prototype was built to fit the K9 rover testbed fielded by NASA Ames. Its working range is 2-6 m, the near distance limited primarily by the height of the rover masthead. The working spectral range is from 240 to ~800 nm, with a resolution of ~2 nm. The YAG laser output is ~100 mJ in ~10 ns pulses, with a repetition rate of 0.1 Hz, limited by thermal considerations.

The prototype was integrated with the rover and tested during the combined rover tests at Lunar Lake, NV in May, 2000. Due to the fire at Los Alamos, which resulted in lab closure and evacuation of the entire county, we were not able to support the testing as planned, and obtained only limited data at the test site. A portion of a spectrum obtained using a single laser shot during the field test is shown in Fig. 2. Joint Wash. U./LANL comparison of reflectance spectroscopy, XRF, and LIBS results are planned as follow-up work on a dozen rocks taken from the site.

Calibration data were taken at several stand-off distances prior to the rover exercises. Samples con-

sisted of standard rock powders. Fig. 3 compares a portion of the spectrum containing Mg and Si peaks for rock powders of pyroxenitic, basaltic, and granitic compositions. Spectra from 10 laser shots were averaged, with a stand-off distance of two meters.

Envisioned Applications: The results show that semi-quantitative elemental compositions are rapidly obtainable at stand-off distances using an instrument of this format. "Quick-look" compositions of rocks and soils some distance from the rover provide a rapid way to determine a) which direction a rover should travel and b) where to use more time-consuming in-situ analysis techniques.

Rapid, stand-off analysis is only one possible application of LIBS, which could be done either using a compact rover-mounted instrument of ≤1.5 kg with capabilities similar to the prototype, or using a slightly more robust lander-mounted instrument capable of 20+ m stand-off distances, though this is perhaps more applicable to, e.g., a Europa lander. The detector portion of such an instrument could double for Raman spectroscopy analyses [7] to yield mineralogical information at stand-off distances [8] as well. If more quantitative elemental analyses are desired from LIBS, such as to aid in radiometric dating, in-situ analyses using a fiber optic cable mounted adjacent to the sample can be done.

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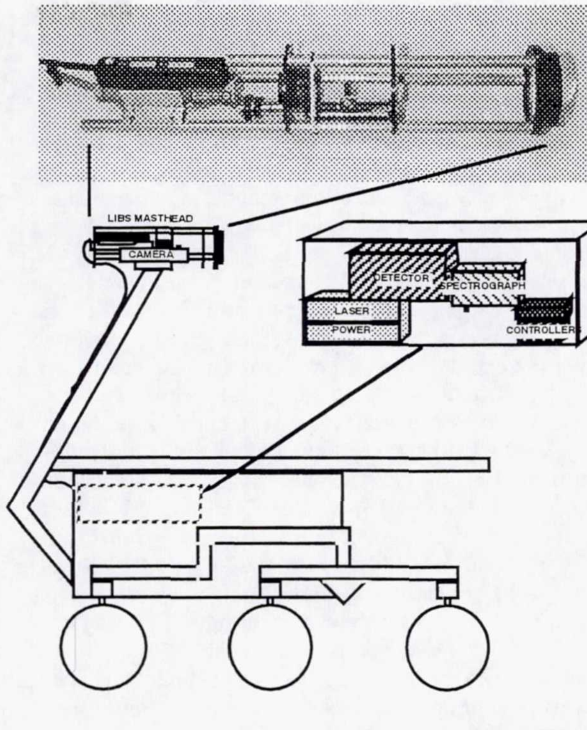

Fig. 1. Schematic view of the LIBS prototype components as mounted in the K9 rover testbed. The photo shows the sensor head with the cover removed. The prototype used only COTS parts, so weight and volume have not yet been optimized.

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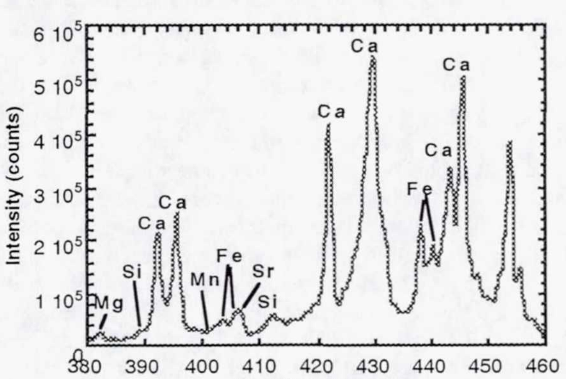

Fig. 2. Spectrum of a basalt rock recorded by the LIBS prototype on the K9 rover during field tests. This spectrum was obtained using a single laser pulse.

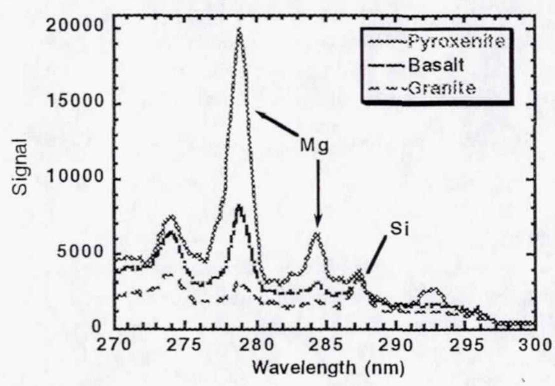

Fig 3. A portion of the spectrum showing two Mg peaks and a Si peak. The three rock types are very easily distinguished from the Mg/Si ratio. Ten-spectra averages were taken on standard rock powders at 2 m. The MgO abundance ranges from 25% to 4% to 0.04%.

A MINIATURE MARS ASCENT VEHICLE. B. H. Wilcox[1], Jet Propulsion Laboratory, California Institute of Technology, M/S 107-102, 4800 Oak Grove Dr. Pasadena, CA 91109, [1]Brian.H.Wilcox@jpl.nasa.gov.

Abstract: Launch of payloads from the surface of the Mars is a central element in any Sample Return program, and represents one of the most important objectives of NASA planetary science and HEDS programs. Analysis of these samples in the sophisticated laboratories of Earth will give vastly more scientific as well as HEDS-relevant engineering and space-medicine knowledge of those bodies than can be performed from any feasible near-term miniaturized instruments. What is proposed here is a launch system with no moving parts of any kind: no gyroscope, no accelerometers, no control surfaces, and no thrust vector control. This concept is an enhancement and improvement based on the formerly-classified PILOT microsatellite launching system developed by the U.S. Navy at the China Lake Naval Ordinance Test Station (NOTS) in 1958. Developed as a crash program in response to the Soviet launch of Sputnik 1, the PILOT all-solid rocket launcher was about an order-of-magnitude lighter than conventional orbital launch vehicles developed before or since, and had no moving parts or control system. With a launch mass of under 1000 kg, it was dropped from the wing of a fighter plane climbing at about 70 degrees from horizontal, and used a first stage to lob it above the atmosphere. It had fins which were slightly canted to make the rocket roll slowly about its axis, giving it a gyroscopic moment. The atmospheric drag acted on the fins to keep the vehicle axis roughly tangent to the trajectory. About 80 Km up, the trajectory became approximately horizontal. An optical detector sensed the horizon, triggering the second stage when the vehicle was approximately horizontal. A third stage was ignited by the burnout of the second stage. These latter two stages together achieved almost the entire Earth orbital velocity of 8500 m/s. A fifth stage was mounted backwards to the other stages inside the payload, initiated by a 53 minute timer. The gyroscopic moment of this oblate payload kept the payload stabilized inertially in space for enough time to go half way around the Earth. The last stage, backwards to the flight direction at launch, kept its inertial direction and was thus pointed forward along the orbital direction on the other side of the orbit. When the timer fired the last stage it gave the "apogee kick" needed to put the satellite into a long-life orbit. This approach was declassified in 1984, and it became known to this author since the originator and project manager of PILOT happened to be this author's father.

The difficulty with this approach is that, in its original form, there is a very limited ability to prespecify the orbital parameters which result from this unguided launcher. Following this author's proposal to use the original PILOT concept for Mars Sample Return in June '98, the concept of using a spin-stabilized upper stage to avoid the need to accelerate a guidance and control system to orbital velocity was adopted as the baseline for the Mars Sample Return mission studies at JPL, reducing the development cost from an estimated $170M to $50M and the mass from 400 kg to about 100 kg. However, there substantially greater benefits yet to be reaped, enabling not only a greatly reduced cost for Mars Sample Return, but also enabling Venus Sample Return, Mars micromission/polar sample returns, Mercury sample return, and low cost lunar polar sample return.

The basic PILOT system is extended and significantly enhanced by three new ideas for this proposed activity: 1) that the aerodynamic tipover of the vehicle at the top of the atmosphere can be modeled as a nonuniform gyroscopic precession and can be accurately predicted and controlled by appropriate selection of the initial conditions of vehicle configuration and launch to give a relatively precise orbit injection, 2) that the final orbit injection stage can be configured around the payload so as to make the total system both oblate (and therefore spin stable for its half-orbit coast up to apoapsis) and to protect the payload from aerodynamic forces (e.g. no separate payload shroud is required), and 3) that the final stage assembly can have a beltline of small, single shot thrusters around its equator to allow correction of whatever orbit insertion errors may occur in the flight of this unguided rocket by use of tracking and remote control commands from the rendezvous vehicle. None of these concepts were incorporated in the PILOT system or any subsequent orbital launch system. A provisional patent application on these innovations has been filed to protect the government interest in these key features which will enable the PILOT concept to be effectively used both for low cost Earth orbital launch of small or large payloads, and some of them enable extremely small and low-cost sample return missions from any of the terrestrial planetary bodies of the solar system.

The key to building a miniature Mars Ascent Vehicle (MiniMAV) which can be put into a precise orbit for rendezvous is to create an integrated orbit injection canister with the following properties: it has an oblate, spin stable mass distribution, it has the return sample along the geometric spin axis, it has a circularization thruster also mounted on the spin axis, and it has a beltline of trim thrusters and a remote control receiver to fire them at specified times to modify the orbit as needed for rendezvous. Figure 1 shows a configuration consistent with these requirements.

The oblate mass distribution is required so that the canister remains spin stable during the half-orbit from the time of the orbit injection burn to the time of the circularization burn at apoapsis, as needed to ensure that the circularization thruster is pointed in the correct direction for that burn. By making the mass distribution oblate, a passive nutation damper can be used to remove the excitation introduced by the inevitable slight offpointing of injection burn. Perhaps the best way to ensure that the mass distribution is oblate is to incorporate the final injection stage into the canister. This last stage will be injected to orbital velocity anyway, and it's extra mass allows greater flexibility in the configuration of the system elements to ensure the needed overall mass properties. Accelerating this spent mass with the circularization burn is less of a penalty than trying to separate from it.

Placement of the planetary sample on the spin axis is needed to ensure that the mass properties of the canister as

a whole are very well controlled, as needed by the uncontrolled flight dynamics of the vehicle. A preliminary study effort has been conducted to evaluate the feasibility of insulating this sample from the thermal pulse of both the injection and circularization rockets and the mass penalty seems acceptable.

The circularization thruster must be on the spin axis of the canister so that there is minimal thrust offset in performing the circularization burn. Placing the circularization thruster in front of the sample and making it the access point for sample insertion in t he center of the injection stage, as shown in Figure 1, has several advantages. It allows the injection stage to have minimum surface to volume ratio and to be a single nozzle system, so that there are no issues of burn or thrust synchronization or matching which could be catastrophic. Furthermore, it allows the circularization burn to heat the bond line where the sample is inserted to incendiary temperatures, melting a bead of brazing compound around the seal and sterilizing the exterior of the bond line for purposes of planetary protection. The remainder of the spherical surface of the canister can be protected with a frangible bioseal which is blown off by the burn of the various thrusters.

Trim thrusters are arranged around the beltline of the canister. These assist in creating the oblate mass distribution and are key to allowing the canister to perform the bulk of the delta-V maneuvers which are needed to rendezvous with the Earth Return Vehicle (ERV). These thrusters would be fired by remote control from the ERV. Since the ERV must be able to acquire and track the canister, it necessarily has assets such as a beacon receiver and optical tracking camera which can locate the canister. If the canister is painted half white and half black, it will "blink" in the sunlight as it spins. The ERV can then determine the phase of rotation from this blinking optical signature, and use it to time remote control commands for firing of the trim thrusters. Normally these thrusters would be fired at the point of the plane crossing of the two vehicles, and so the vehicles can be very close together at the time that the remote control commands are sent.

Once the canister is in the correct orbit for rendezvous, it consists of a spherical mass of spent rocket motor casings and refractory structure which is all capable of exposure to extremely high temperatures. The fill material between the rocket motors could be composed of material similar to Space Shuttle thermal protective tile. With the sample embedded deep in it's center, it is possible that this canister can be used directly as the Earth entry capsule. The estimated terminal velocity for this assembly in Earth's atmosphere is about 15 m/s. It seems plausible that the canister could be designed to survive impact at this velocity, which would allow the whole rendezvous sample handling chain to be eliminated, greatly reducing the mass and cost of the mission.

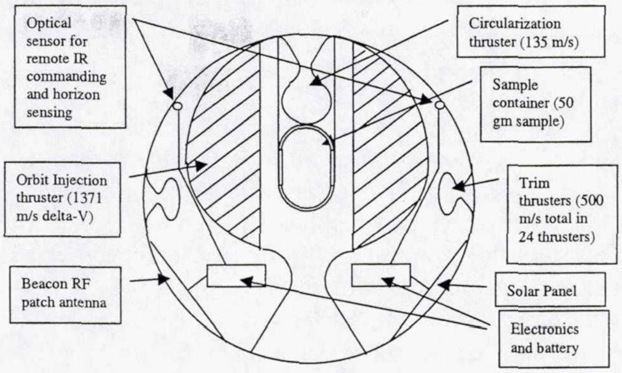

Figure 1: Schematic of Injection Stage Assembly.

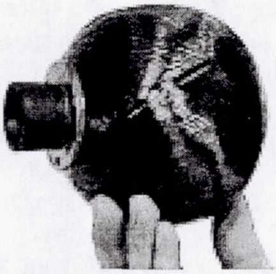

Figure 2: Thiokol Nanosat rocket motor developed for GSFC

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NANOROVERS AND SUBSURFACE EXPLORERS FOR MARS. B. H. Wilcox, Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 107-102, 4800 Oak Grove Drive, Pasadena CA 91109, USA (Brian.H.Wilcox@jpl.nasa.gov).

Abstract: Recent advances in microtechnology and mobile robotics have made it feasible to create extremely small automated or remote-controlled vehicles which open new application frontiers. One of these possible applications is the use of nanorovers (robotic vehicles with a mass of order 1 Kg or less) in planetary exploration. NASA and Japan's Institute of Space and Astronautical Science (ISAS) are cooperating on the first mission to collect samples from the surface of an asteroid and return them to Earth for in-depth study. The ISAS MUSES-C mission will be launched on a Japanese launch vehicle in July 2002 from Japan toward a redezvous with the asteroid 1989ML in September 2003. A NASA-provided nanorover will conduct in-situ measurements on the surface. With a mass of about 1kg, the rover experiment will be a direct descendant of the technology used to build the Sojourner rover. The rover will carry three science instruments: a visible imaging camera, a near-infrared point spectrometer and an alpha X ray spectrometer. The solar-powered rover will move around the surface of 1989ML collecting imagery data, which are complimentary to the spacecraft investigation. The imaging system will be capable of making surface texture, composition, and morphology measurements at resolutions better than 1 mm. The rover will transmit this data to the spacecraft for relay back to Earth. Due to the microgravity environment on 1989ML, the rover has been designed to right itself in case it flips over. Solar panels on four sides of the rover will ensure that enough power will always be available to the rover to activate the motors needed to turn over. Posable struts will allow the rover to position its chassis such that the camera can be pointed straight down at the surface or straight up at the sky.

The rover has been designed with the capability to right itself if it flips onto its back. Since the four posable struts are independent, the rover can be commanded to point itself in any orientation. A pointable mirror and actuated focus mechanism allow the rover to take panoramic images as well as microscopic ones.

The primary rover science objectives are to carry out scientific measurements with its entire instrument suite and to transmit the data before asteroid "night," at which time, the rover will shut down until sunrise. There is little non-volatile storage on the rover. Most data not transmitted to the orbiter at the end of the daily investigation schedule will be lost. Daily investigations include visual imaging of the terrain and targets of interest, point spectra in the infrared, AXS spectra, and soil mechanics investigations using the rover as an instrument.

The rover consists of a rectangular body, which is 14 14 × 6 cm in dimension with four wheels on four posable struts for mobility. The wheels are 6.5 cm in diameter, mounted on struts, which extend in pairs from hubs emerging from the geometric center of two opposing 14 × 6 cm faces of the body. Each strut is 7 cm long from the center of their pivot to the center of the wheel axis. Four of six faces of the rover body have solar cells for power generation. The top face also has the antenna element needed to transmit the radio signal. The rover can communicate as long as it is powered, with a line-of sight range of about 20 km.

The rover has optical detectors on all six orthogonal exterior faces of the rover. Using these detectors, the rover will be able to determine the direction to the sun. Vertical sensing is not possible due to the unavailability of accelerometers which can measure the microgravity fields of asteroids and yet fit within the mass constraints of the rover. The rover has a laser range finder, which enables it to determine the range to nearby objects. This serves a similar function to the mast-mounted stereo lander cameras used in conjunction with the Sojourner rover to localize the 3-D positions of science and engineering targets, hazards, and other objects.

The rover carries three science instruments, the visual camera, the near infrared spectrometer and the alpha X ray spectrometer. There is view window on the front face for the camera and IR spectrometer. The AXS sensor will open out to the rear of the rover and be placed in contact with rock or regolith by appropriate body/strut motion.

The entire rover system is being qualified for the temperature range of -180°C to +110°C, which is derived from the worst case situations during the mission. The mechanical environment for the rover is dominated by the vibration environment imposed by the ISAS MV launch vehicle. The MV is an "all solid" design and, as such, provides a relatively "rough ride". To be conservative, the mechanical elements of the rover are being designed to 100Gs and the OMRE to 125Gs. The entire rover is also being designed to be compatible with a radiation dose of about 25krad, although many components will tolerate much higher levels.

Application of the nanorover to Mars is straightforward: indeed the research program under which the basic technology of the nanorover was created had Mars as the original target. Although the solar power density is less on Mars than on the MUSES-C mission target, the lower operating temperature of the solar panel should cause the amount of power available on Mars to be comparable or greater than that on the asteroid. The only hardware modification needed for Mars is the inclusion of brakes on the mobility actuators so that the vehicle can "park" without rolling or changing pose. Fortunately, accomodations for these brakes are already included in the nanorover design.

Another small robotic vehicle, the Subsurface Explorer (SSX), is being developed at the Jet Propulsion Laboratory which is suitable for exploration of the deep underground environments on Mars. The device is a self-contained piledriver which uses a novel "spinning hammer" technology to convert a small continuous power feed from the surface over a two-wire tether into a large rotational energy of a spinning mass. The rotational energy is converted to translational energy by a novel mechanism described here. The hammer blows propagate as shock waves through a nosepiece, pulverizing the medium ahead of the SSX. A small portion of the pulverized medium is returned to the surface through a hole liner extending behind the SSX. This tube is "cast in place" from two chemical feedstocks which come down from the surface through passages in the hole liner and which are reacted together to produce new material with which to produce the hole liner. The lined hole does not need to be the full diameter of the SSX: approximately 100 kilograms of liner material can create a tunnel liner with a 3 mm inside diameter and a 6 mm outside diameter with at total length of 4 km. Thus it is expected that core samples representing an overlapping set of 3-mm diameter cores extending the entire length of the SSX traverse could be returned to the surface. A pneumatic prototype has been built which penetrated easily to the bottom of an 8 meter vertical test facility. An electric prototype is now under construction. It is expected that the SSX will be able to penetrate through sand or mixed regolith, ice, permafrost, or solid rock, such as basalt. It is expected that an SSX approximately 1 meter long, 3-4 cm in diameter, and with a power budget of approximately 200 Watts will be able to explore up to ~5 kilometers deep at the rate of about 10 meters per day. A preliminary subsurface exploration mission could be conducted as early as 2005, with penetration of hundreds of meters to characterize the local gradients of temperature and redox potential and perhaps locate the top of the cryosphere, for example.

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THE IMPORTANCE OF BRINGING SAMPLES OF MARS TO EARTH.

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Introduction: A basic goal of the Mars Surveyor Program, begun in 1996, was the delivery to Earth of carefully chosen samples of Mars surface material. Interest generated by the proposition that Mars meteorite ALH84001 displays evidence of extraterrestrial life, also put forward in 1996, intensified interest in the Mars Surveyor Program in general and sample return in particular. As we all know, however, the character of the projected Surveyor program has changed dramatically with the failures of the Mars Climate Orbiter and Mars Polar Lander missions and the realization that ambitious goals must be scaled back. Most notably, the concept of sample return from Mars has all but disappeared from the dialogue about Mars exploration in the next decade. Remote analysis of surface materials by instruments on landed rovers is offered as the next-best option.

This paper argues that remote analysis is not even in the same league as the study of samples in terrestrial laboratories, and that every effort should be made to fulfill the goal of sample return at the earliest opportunity. Remote analysis is inferior to laboratory study in two fundamental ways.

1. Scale: To date, remote analysis of planetary materials has been limited to measurements of some of their bulk properties. This is a very crude tool to have to rely on. For the better part of 200 years Earth rocks have been studied at the microscopic level, and the same is true of meteorites and (when they became available) lunar samples. Most of what we know about terrestrial and extraterrestrial rocky materials has come from imaging at the microscopic level, and in recent decades from the use of microbeam instruments to reveal microchemical structures and isotopic patterns in these materials. The machinery required to prepare materials for these studies and perform the analyses is complex and massive; it does not lend itself to miniaturization for spacecraft payloads. Undoubtedly a time will come when simple forms of microanalysis become possible on remote planetary surfaces, but these portable techniques will always lag far behind what is possible in terrestrial laboratories.

The microscopic study of sections of rock, or soil particles, lays open a wealth of detailed information that cannot be obtained by bulk analysis. Examples are shown in Figs. 1 and 2, which are thin sections of terrestrial sedimentary rocks, illuminated by transmitted light. Our choice of sedimentary rocks is in the spirit

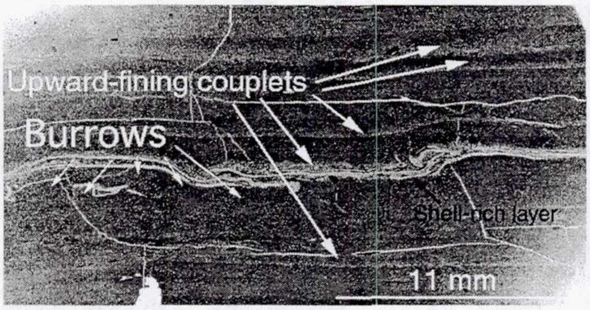


Figure 1. Thin section of the Kildonnan Member mudstone, Mid-Jurassic, Scotland. Courtesy of Joe Macquaker, Manchester University, UK.

of the recommendation of [1] that such materials should have a high priority in sampling Mars, because of the importance of the search for past or present life there, and evidence they would contain of the climate and volatile history of Mars.

Figure 1 shows a mudstone consisting mostly of <50 μm particles of clay and other minerals. Each "upward-fining couplet" in the section records a discrete paleoclimatic episode on Earth— a storm— in which a batch of muddy water entered the volume where this rock originated and the mud settled, coarser grains while the stream flow was fast and finer grains as it slowed. The individual grains contain information about source rocks in the drainage area where they originated, far upstream. Microbeam analysis techniques have advanced to the point where a very large amount can be learned, *in terrestrial laboratories*, from a single 10-μm mineral grain (Fig. 3).

Note that one episode during the time when this rock was being assembled deposited a thin layer of fossil shell fragments, and that during quiescent periods bottom-dwelling organisms burrowed into the sediment surface. The relevance of these microscopic features to stream-laid martian rocks is, of course, unknown.

Figure 2 is a section of a terrestrial *wacke*, or poorly-sorted sandstone, a coarser class of sediment that forms close to the source of its components. Because little stream transport is involved, size-sorting has been minimal. The presence of relatively large (mm-scale) particles in such rocks is important because samples this large can be polymineralic, and ion microprobe study of the isotopic structures in their constituent minerals can yield radiometric ages of the source rocks. (The same is true of rock particles in soil samples.)

Figure 2. Thin section of graywacke from the Carboniferous Anaiwan Terrane, Australia. Width of field, 5 mm. Coarse mineral clasts are plagioclase, orthoclase, quartz, and hornblende. Arrows point to dacitic and andesitic lithic clasts. Courtesy of Bill Landenberger, Univ. Newcastle, Australia.

2. Adaptability: When analytical instruments are miniaturized for flight payloads, it is at the expense of versatility and repeatability. The optimal type of measurement, and the range of parameter space to be explored, must be prejudged. If an inappropriate measurement is chosen (as in the case of the Viking life detection experiments), the error cannot be corrected. If what is learned points to the importance of other wavelength ranges, or greater sensitivity, or some other change in instrumentation, typically this must wait for a later mission.

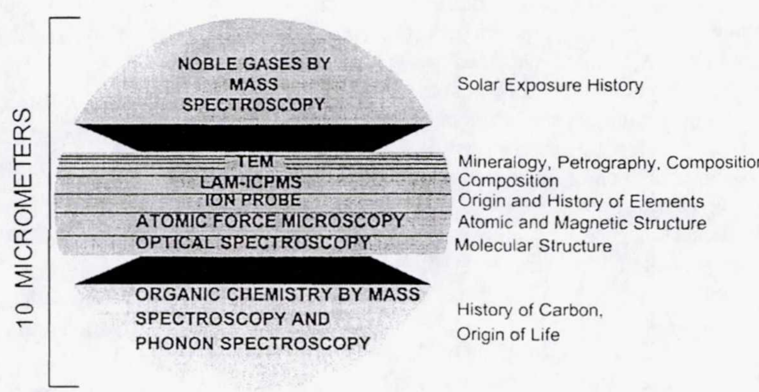
Science, by its very nature, is exploratory and iterative. Each result obtained poses another question and points to a new type of measurement. The learning path consists of many steps of this sort. In a terrestrial laboratory such a path can be followed for years through its many iterations, especially now that many measurements can be made with so little consumption of material (Fig. 3). This is not possible with remote spacecraft measurements. Even in cases where there might be enough flexibility in the instrumentation to accommodate additional iterations, the duration of experimentation is limited by the supply of expendables and the lifetime of spacecraft components.

Concluding remarks: It is instructive to compare two contributions that spacecraft made to our knowledge of the moon. Surveyor 5, in 1966, made bulk analyses of the surface of Mare Tranquillitatis. It was a completely successful mission, and the analyses confirmed the basaltic character of lunar maria. But we know vastly more than this about the moon now, and our rich knowledge of that body has come almost entirely from the samples that were brought to terrestrial laboratories by the Apollo astronauts. Without laboratory studies we could not know the ages of rocks and the chronology of events on the moon, or the petrologic nature of terra rocks and the processes that created them, or the rare-earth patterns in lunar basalts that informed us of the moon's internal evolution, or many other important properties of the moon.

Our understanding of Mars will be similarly retarded until we can study samples of that planet in terrestrial laboratories.

[1] Mars Program Architecture: Recommendations of the NASA Astrobiology Institute, 1/10/00. [2] Zolensky, M. E. et al. (2000) *MAPS* **35**, 9-29.

Figure 3. Hypothetical study of a single 10-μm sample of extraterrestrial material which has been sliced by a microtome and studied by a consortium of terrestrial laboratories. Figure from (2).



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IMMERSIVE ENVIRONMENT TECHNOLOGIES FOR MARS EXPLORATION

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Introduction: JPL's charter includes the unmanned exploration of the Solar System. One of the tools for exploring other planets is the rover as exemplified by Sojourner on the Mars Pathfinder mission. The lightspeed turnaround time between Earth and the outer planets precludes the use of teleoperated rovers so autonomous operations are built in to the current and upcoming generation devices. As the level of autonomy increases, the mode of operations shifts from low-level specification of activities to a higher-level specification of goals. To support this higher-level activity, it is necessary to provide the operator with an effective understanding of the in-situ environment and also the tools needed to specify the higher-level goals. Immersive environments provide the needed sense of presence to achieve this goal.

Use of immersive environments at JPL has two main thrusts that will be discussed in this talk. One is the generation of 3D models of the in-situ environment, in particular the merging of models from different sensors, different modes (orbital, descent, and lander), and even different missions. The other is the use of various tools to visualize the environment within which the rover will be operating to maximize the understanding by the operator. A suite of tools is under development which provide an integrated view into the environment while providing a variety of modes of visualization. This allows the operator to smoothly switch from one mode to another depending on the information and presentation desired.

Terrain Modelling: The creation of 3D models of the in-situ environment begins with imagery collected by orbiting instruments which utilize stereo image processing to generate elevation maps of the terrain. Viking data has produced such elevation maps for the vast majority of Mars that are georeferenced and registered with imagery. This provides a baseline model for the 3D representation of a given operational area. Descent imagery captured by a lander is the next input and this is processed by unique methods developed at JPL to generate elevation and landmark maps of the landing area. The descent images provide lower resolution data over a large area and higher resolution data in the immediate area of the lander. The elevation maps produced from the descent imagery are then registered with the baseline dataset to create a multiresolution, georeferenced image and elevation map set.

The final piece of data is captured by the lander/rover. The stereo imagers on the lander capture the immediate surroundings at very high resolution. However, it is difficult to utilize standard image processing methods to attempt to register the lander images to the baseline model. This is due to the extreme difference in position and pespective that a lander on the surface has relative to an orbiter or other airborne instrument. The lander can image areas under overhanging boulders or other structures that are invisible in the previous datasets. To circumvent this problem, the registration process takes place in 3D utilizing the geometry of the baseline dataset to register with the geometry of the surroundings generated by stereo processing of the lander imagery. This process is well supported by the use of voxels and octrees which provide inherent multiresolution dataset support with relatively low storage requirements.

The generation of 3D models for the lander site is a process described by Ivanov, et al [1]. The process uses image correlation processes to register all the images captured by the lander cameras into a panoramic mosaic. This provides for correction of camera pointing errors. Registering the resulting 3D models to the baseline geometry provides an additional correction computation to make further improvements in pointing data and to register the models to the baseline geocoordinates. For a rover, this process can be iterated as the vehicle travels to new locations and captures stereo imagery of the surroundings. Each patch can be registered to the baseline model and the entire set of data maintained in a cohesive fashion.

Immersive Planning Tools: During Pathfinder, the terrain models built from the IMP imagery extended a few meters out from the lander. If the operators wanted to traverse to a location outside this region, there was no model and no imagery to assist them in planning the sortie. With the multiresolution datasets described above, there will be models with varying resolution extending across the entire planetary surface, or at least multiple kilometers. This will allow the operators to plan traverses to previously unexplored areas with more assurance of traversability and reduced mission risk.

As rovers gain autonomy, the sortie planning process shifts from a low level specification of commands to a higher level specification of goals. These higher level specifications will include such things as traverse to a waypoint and activate instrument at this location. The role of the operators will include more analysis of the in-situ conditions and rover state and less low level control of behavior. The Rover Control Workstation (RCW) under development provides a variety of tools, in an integrated environment, to provide the operator with the greatest understanding of the in-situ environment and rover state possible. Multiple visualization modalities, combined with a robust message passing environment, provide common views into the in-situ environment and planned activities. In addition, collaborative sortie planning operations are supported.

The RCW deployed for the Pathfinder mission was based on two basic visualization tools, the Stereo View and the Flying Camera View as described by Cooper [3]. These two

basic modalities are continued in the updated version and combined with a Map View tool to provide the most important visualization functions of the in-situ environment. The Stereo View mode provides the most basic, raw look at the image data returned from the stereo imagers. The imagery is displayed using a stereo monitor with the individual stereo pairs arranged in position relative to the camera pointing when the images were captured. Use of stereo glasses provides the operator with a view of the data in its least processed form. Depth and other stereo cues allow the operator to get a fundamental feel for the environment. The minimal level of processing ensures that no artifacts have been added to the data and that no important features have been hidden.

One problem with the Stereo View tool is that it is very difficult for a human to judge the separation of objects in the foreground and background so as to decide if the rover can fit between two rocks. The Flying Camera tool alleviates this problem by providing a means to examine the in-situ environment from any vantage point. The stereo imagery from the imagers is processed to generate a 3D model of the terrain in the immediate vicinity. This model is stored in a form that can be loaded and visualized with a high level of detail and interactive rendering rates. The camera can then be positioned to view possible routes and constrictions to verify that the rover can indeed traverse the planned route. The Flying Camera tool also supports visualization of a model of the rover that can be positioned anywhere within the environment to verify fit and feasibility.

The Map View tool adds a natural, maplike visualization mode to the suite of tools in the RCW. Consisting primarily of descent imagery, the Map View tool displays the sortie planning area from above at various resolutions depending on the availability of data. It also provides natural access to georeferencing information and to navigation data such as landmark datasets, reference points, and direction. It is easy to lose direction in the Flying Camera tool but the Map View tool displays a compass indicating North when desired. Another indicator points to a specified reference point, such as the lander, to make it easier to navigate samples back to a return vehicle, even when out of sight of the lander. Other features of the Map View tool include specification of hazard or protected regions and contour lines for analysis of slope.

The other main component of the RCW for sortie planning is the Activity Editor which is essentially a text visualization tool for displaying the sequence of commands being produced. All four tools are integrated with a message passing executive which maintains a consistent view of the planned sequence among all the tools. Commands, such as traverse to waypoint, may be specified in any of the tools and the creation or editing of such a command is immediately reflected in the other tools. Additionally, multiple copies of each visualization tool may be launched by the same executive yet running on distributed systems to provide for a collaborative planning environment.

Other tools to be integrated within the RCW include a Telemetry Visualization tool to review the previous period's activities as reported by the rover and a Sortie Rehearsal/Simulation tool to perform dynamic simulations of the planned sorties. Comparison of expected behavior to reported behavior can provide important clues to rover performance.

References:

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[2] Ivanov, A., Lorre, J., and Maki, J., Image analysis for robotic exploration of Mars, ibid.

[3] Cooper, B., Driving on the Surface of Mars Using the Rover Control Workstation, , proceedings of SpaceOps '98, Tokyo, Japan, June, 1998..

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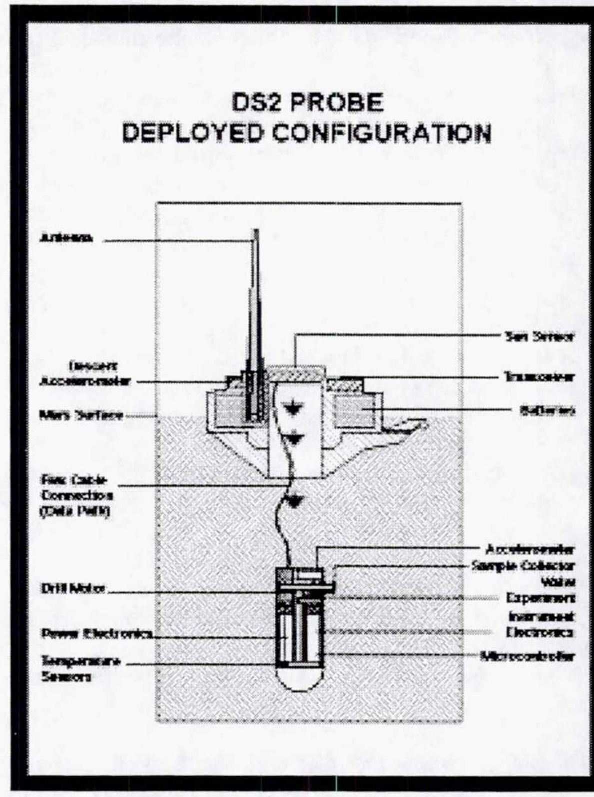
SUBSURFACE SCIENCE FROM A PENETRATOR. A. S. Yen, Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, MS 183-501, Pasadena, CA 91109; Albert.Yen@jpl.nasa.gov).

Introduction ("WHY?"): Much of what we know about the geologic history and present state of Mars is based upon interpretations of data collected from the immediate surface. Unweathered soil samples covered by dust and sand sized particles may provide clues about the role of water and the biological history of the planet. The use of drills and scoops to obtain such samples for lander-based instruments implies the development of relatively large, sophisticated platforms. Small (several kilograms), scientifically focussed penetrators can carry instruments to the subsurface and should be included in the Mars exploration strategy.

Penetrator Platform ("HOW?"): One of the primary objectives of the Deep Space 2 (DS2) Microprobes was to demonstrate the ability to collect and analyze a subsurface sample. Unfortunately, neither of the probes returned data after impact with the martian surface on December 3, 1999. Options for validating the DS2 technologies by retesting aspects of the system are currently being explored. Thus, it is reasonable to expect sufficient testing heritage to conduct a penetrator-based scientific investigation for launch in 2005.

Regardless of the lander or orbiter platforms selected for upcoming launch opportunities, a small penetrator is an ideal piggyback payload and can significantly enhance the scientific return of the mission. The DS2 system consisted of a single stage entry system (~1.2 kg), an aftbody that remained on the surface to provide the telecommunications link (~1.8 kg), a forebody to conduct the subsurface science (~0.7 kg), and the interface hardware to the cruise ring (~2.9 kg). In this design, a subsurface sample is collected by a small drill, sealed by a pyrotechnic actuator, resistively heated, and analyzed for water content by thermal and spectroscopic techniques. An accelerometer was included to provide information on the actual depth of penetration. Thermal conductivity and atmospheric structure measurements were also intended.

Scientific Investigations ("WHAT?"): Here, I present two specific subsurface investigations relevant to water and biology that are compatible with a DS2-like penetrator. These investigation concepts are based upon existing technologies and could be launched as early as 2005 ("WHEN?").



History of water. Images of canyons, valley networks, and outflow channels indicate that liquid water played a significant role in developing the martian geomorphology. However, geochemical evidence in support of a sustained presence of liquid water at the surface is absent. Perhaps the strongest evidence against aqueous weathering of the exposed martian surface is the detection of extensive deposits of unaltered pyroxenes by the MGS thermal emission spectrometer [1]. In a water-rich environment, pyroxene surfaces would be rapidly converted to secondary mineral phases such as clays. Based upon terrestrial weathering rates [2], a 100 micron layer of alteration products would develop on pyroxene surfaces in less than 10^4 years. The apparent absence of clay minerals, carbonates, and hydrated mineral phases challenges the possibility of a "warm and wet" past. Where are the mineralogical markers associated with the putative aqueous history? Is it possible that they are preserved beneath the immediate surface?

A penetrator could provide access to subsurface samples and allow a direct search for indications of

past aqueous episodes. The DS2 system provided a method for collecting, heating, and analyzing samples from a depth of approximately 0.5 meters, and minor modifications to this design could be applied to achieve higher temperatures and deeper penetration. Endothermic phase changes and water loss from the soil sample which are diagnostic of hydrated mineral phases can be recorded with temperature sensors and a laser spectrometer similar to DS2. Gypsum, for example, dehydrates at approximately 65 ℃ and 100 ℃, interlayer water can be released from clays between 150 ℃ and 250 ℃, lepidocrocite dehydrates near 300 ℃, goethite evolves water between 350 ℃ and 400 ℃, and certain clays such as nontronite can dehydroxylate at temperatures as low as 450 ℃. Thus, a penetrator with thermal and evolved gas instrumentation could be sent to suspected lacustrine or evaporite units to analyze subsurface samples for the presence of hydrated mineral phases. A positive detection would obviously provide valuable information on the history of water on Mars.

Biocompatibility. The biology experiments onboard the Viking Landers did not detect evidence of life in the soil. In fact, the data revealed an unexpectedly reactive surface environment where organic molecules are actively destroyed by one or more unidentified oxidants in the soil [3]. An understanding of the composition and reactive nature of these chemical species would help guide the search for biological molecules and would allow implementation of appropriate countermeasures for minimizing the risk to humans on Mars. Are these oxidants contained in a shallow (<25 cm) surface layer, or do they extend to depths of multiple meters? How deep do we need to go to have a good chance of finding primitive biomarkers on Mars?

A penetrator providing access to the subsurface would be ideal for determining the vertical extent and variability of the oxidizing species. A sensor technique based on thin-film, metallic chemiresistors is well suited for measuring small changes in oxidizing potential. These chemical sensors are good conductors when unreacted and excellent insulators when oxidized to any of the stable oxides. Thin layers (~100 Å) of metal rapidly exhibit dramatic resistance changes when small fractions of a monolayer of metal are converted to metal oxide [4]. An array of chemiresistors in the forebody sample cup can be compared to a similar set in the aftbody to characterize the reactivity changes with depth. In addition to this gradient information, the rate of oxidation of the different thin-films in the array can provide constraints on the composition of the oxidizing species. Characterizing the vertical distribution and the composition of the reactive component in the soil is essential for understanding the biocompatibility of the surface.

Summary: A variety of scientific investigations including the search for water and unoxidized biomarkers are enabled by access to subsurface samples. A penetrator with minimal resource requirements can be carried to Mars as a piggyback payload to pursue these high-priority questions and can significantly enhance the scientific return of the primary mission.

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WATER-SEARCHERS: RECONFIGURABLE AND SELF SUSTAINING ARMY OF SUBSURFACE EXPLORATION ROBOTS SEARCHING FOR WATER/ICE USING MULTIPLE SENSORS.

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Objectives: Perhaps the most promising site for extant life on Mars today is where subsurface water has been maintained. Therefore, searching for underground water will provide a good chance to find evidence of life on Mars. The followings are scientific/engineering questions that we want to answer using our approach:

1. Is there subsurface water/ice? How deep it is? How much it is? Is it frozen?
2. What kinds of underground layers exist in Martian crust?
3. What is the density of Martian soil or regolith? Can we dig into? Should we drill into?
4. Can a sudden release of underground water happen if a big asteroid hit the Mars?

Our approach will be able to provide essential information to answer the questions. Moreover, dependent on the water content and depth in soil, not only resultant scientific conclusions but also proper digging/drilling method can be suggested. "How much water in the Martian soil?" There can be several possibilities: large water content that is enough to form permafrost, or small water content that is not enough to form permafrost, or different layers with different moisture contents. "How deep a rover should dig into soil to find water/ice?" The exact size-frequency distribution has not been measured for the soil particles. On-board sensors can provide not only the water content but also the density (or porosity) of Martian soil as a function of depth.

Step-by-Step Approach down to an Army of Remote Sensing Rovers: Finding underground water on a planet like Mars would be much more difficult than finding it under our own desert since there is no rain on Mars. It is unlikely to find underground water by simply touching down a craft on Mars and digging several feet at that location. Instead, step-by-step approaches, starting from remote sensing (several hundred km resolution) using satellites, then aerial searches (less than one km resolution) using airplane, and narrowing it further down with ground searches over the area (less than a couple of m resolution) using rovers as shown in Figure 1, will increase the chance of finding water/ice drastically. Even with rovers, it is almost impractical to drill holes randomly here and there over the wide area of coverage looking for a water/ice signature. It is very time consuming and impractical to drill/core continuously over the wide area to find potentially low fraction of water/ice without an initial aerial survey. Therefore, a step-by-step approach down to rovers to pin point the most probable location to find water/ice is suggested.

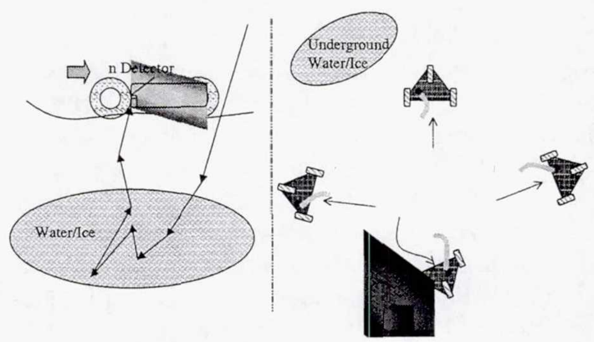

Figure 1. Surface mobile platforms with sensors to survey underground water/ice layers.

Subsurface Direct-Characterization: a Digger: One of the primary purposes of the rover with water sensors is for the initial survey of water/ice tables over the wide area near a landing zone before one set of drilling/coring effort begins. A rover with various sensors will search the area to find water/ice. Once a rover finds a considerable amount of hydrogen, the survey rover will be reconfigured to a digger (the lower part of the survey rover) and a surface (solar power/communication) module (the upper part of the survey rover). The digger, packed with sensors, can go down into subsurface. On Mars or other planets, using a conventional penetrometer has many limitations in penetrating deep into soil due to various constraints. A potential solution can be a self-propelled drill (the digger). The configuration will enable not to drill most rocks but to go around it to save power and to penetrate deep. With sensors housed in the digger, the digger can measure soil moisture contents and soil density at an underground location.

Advantages/Benefits: The idea is unique in that it can search a wide area for water/ice and provide initial survey data –i.e. most probable location to find water/ice -- for penetration/drilling/coring tasks. Due to sensors' high penetrating power to non-hydrogen materials such as dry soil, the suggested approaches are ideal to detect water/ice underneath of a soil layer of the Martian surface. The suggested system can also provide scientifically valuable information such as soil density, subsurface structure, composition, etc. The scientific information about subsurface soil properties and about geological findings will open the new insight into the understanding the geological and climate history of planets and advance the autonomous scientific exploration technology for space science and the human exploration of space drastically.

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 Pg 2

USE OF VERTICAL LIFT PLANETARY AERIAL VECHICLES FOR THE EXPLORATION OF MARS.
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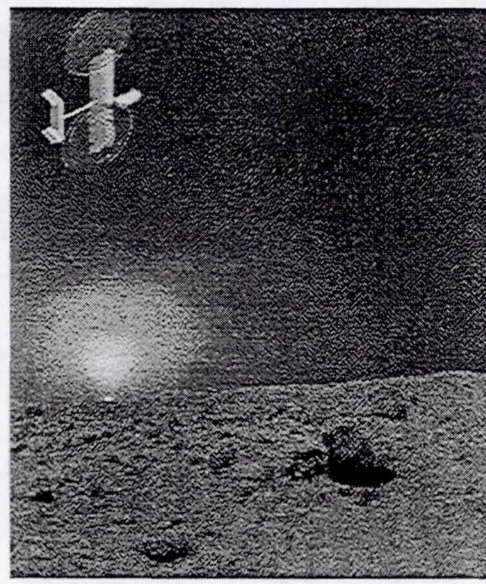
Introduction: Despite the thin, cold, carbon-dioxide-based atmosphere of Mars, recent work at NASA Ames has suggested that vertical lift (based on rotary-wing technology) planetary aerial vehicles could potentially be developed to support Mars exploration missions [1]. The use of robotic vertical lift planetary aerial vehicles (VL PAVs) would greatly augment the science return potential of Mars exploration. Many technical challenges exist in the development of vertical lift vehicles for planetary exploration. It only takes the realization that the world altitude record for a helicopter is less than 40,000 feet (versus flight at the equivalent terrestrial altitude of over 100,000 feet required to match Mars' surface atmospheric density) to appreciate the aeronautical challenges in developing these vehicles. Nonetheless, preliminary work undertaken at NASA Ames and others [2,3] suggest that these vehicles are indeed viable candidates for Mars exploration.

Why vertical lift vehicles for planetary exploration? For the same reason these vehicles are such flexible aerial platforms for terrestrial exploration and transportation: the ability to hover and fly at low-speeds and to take-off and land at unprepared remote sites. Further, autonomous vertical lift planetary aerial vehicles would have the following specific advantages/capabilities for planetary exploration:

- Hover and low-speed flight capability would enable detailed and panoramic survey of remote site(s);
- Vertical lift configurations would enable remote-site sample return to lander platforms, and/or precision placement of scientific probes;
- Soft landing capability for vehicle reuse (i.e. lander refueling and multiple sorties) and remote-site monitoring;
- Hover/soft landing are good fail-safe 'hold' modes for autonomous operation of planetary aerial vehicles;
- Vertical lift planetary aerial vehicles would provide greater range and speed than a rover while performing detailed surveys;
- Vertical lift planetary aerial vehicles would provide greater resolution of surface details, or observation of atmospheric phenomena, than an orbiter;
- Vertical lift vehicles would provide greater access to hazardous terrain than would be provided solely by lander or rover.
- Could act as 'Astronaut Agents' for efficiently and comprehensively conducting scientific exploration.



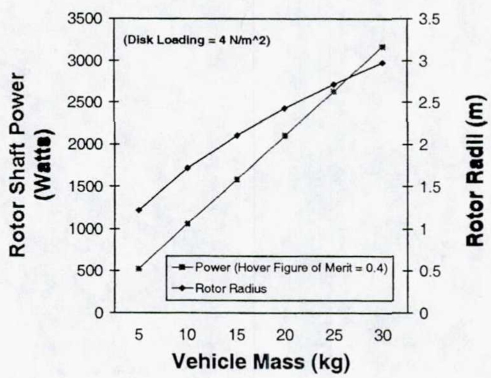
Exploration With a Vertical Lift Component

Opportunities & Challenges:.

Opportunities. Robotic Martian rotorcraft are unique compared to other proposed aerial platforms (aerostats and fixed-wing airplanes) for Mars exploration. The very nature of such a vehicle would be its ability to fly close to and interact with the Martian surface. As was once humorously noted, no one is likely to build runways on Mars. Nonetheless, it is the expectation of the authors that an abbreviated sort of 'evolution of flight' will occur on Mars: balloons will likely be flown first, followed by fixed-wing aircraft, and then rotary-wing/vertical-lift vehicles. These various types of aerial platforms will likely be complementary to each other in their ability to meet unique mission requirements and science objectives. Robotic missions using Martian rotorcraft could include aerial survey work, precision placement of small science probes (or micro-rovers) on the planet's surface, or even support sample return missions by acquiring/retrieving small

soil samples from remote sites. Martian rotorcraft could also support the human exploration of Mars. Martian autonomous rotorcraft could act as 'astronaut agents' for the future explorers providing them improved 'mobility' -- and safety.

Technical Challenges. Autonomous vertical lift PAVs will be high-risk and high-payoff development ventures. Though an impressive – and ever-expanding -- amount of data exists for Mars, nonetheless, these data are barely adequate for the purposes of designing and building PAVs. Such vehicles will need to be highly adaptive (from a controls and structures perspective), have conservative performance margins, and will require high degrees of mission/flight autonomy to adequately deal with corresponding levels of uncertainty in the mission and flight environment. Martian autonomous rotorcraft by their nature will have large lifting-surfaces and will be required to have ultra-lightweight construction. This in turn will pose a challenge in making them sufficiently robust to operate in the Martian environment.



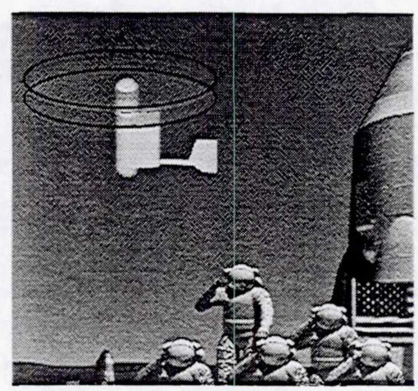
Large, Ultra-lightweight, Fragile...

Early 'Scout' Missions: As noted above, early missions for Martian autonomous rotorcraft will undoubtedly be for aerial survey of the Martian surface. One such aerial scouting mission could focus on mapping a survey area inclusive of the entry error ellipse projected for a follow-up mission.

Two concepts are currently being assessed at NASA Ames for an aerial scout role: an air-deployed autorotating, or partially-powered, 'reelable' rotor design [4,5], and a lander-based, surface-launched, coaxial helicopter design with folding/telescoping rigid blades. Propulsion options include hydrazine 'tip-jets' for the reelable rotor design, and electric motors, or an Akkerman hydrazine reciprocating engine [6], for coaxial helicopter.

Current Status of Work at NASA Ames: Work to date has focussed on conceptual design studies. As a result, reference [1] provided an initial discussion of the technical challenges and opportunities of vertical lift PAVs. In addition to the vehicle studies, a university grant was initiated to develop a conceptual design of a mission/flight control computer architecture for a Martian autonomous rotorcraft. The Year 2000 American Helicopter Society Student Design Competition was initiated focusing on the design topic of a Martian autonomous rotorcraft. Paper design studies from the participating universities have been received and are currently being reviewed by the competition judges. The winning teams of this competition will be announced at the next Annual Forum of the American Helicopter Society.

Ongoing work is focused on the refinement of Ames-generated MARS conceptual designs, as well as initiating development of low-cost proof-of-concept test articles for demonstrating critical MARS technologies – including the development of a hover test stand for testing full-scale rotors at Mars atmospheric densities and a tethered hover flight demonstrator.



Martian Rotorcraft as 'Astronaut Agents'

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